The Earth Sheltered Owner-Built Home

Barbara and Ken Kern
Jane and Otis Mullan

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Mullein Press/Owner-Builder Publications

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Box 817
North Fork, CA 93643

Library of Congress Catalog Card: 82-099912

ISBN 0-910225-00-1

Printed in the United States of America

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How to use the book. The Kern, Mullan, and Zanetto chapters portray theoretical design and practical technique. Non-conventional building methods and approaches to owner-building are discussed in sufficient detail so the reader might proceed to experiment with some of the processes. If you are primarily interested in the theoretical aspects of underground design, read the appropriate portions of these chapters---Design, Waterproofing, and Conclusions---together with the illustrations before studying the particulars.

Dedicated to our parents,
and to all people who are working
to create a sustainable society.

Acknowledgments

We wish to thank the many people who helped make this book possible, and especially the following:
Our admiration and gratitude go out to Ricardo and Loraine Forestiere who preserve the Underground Gardens for all to enjoy and who provided us with photos and information on Baldasare Forestiere.
We are indebted to Jim and Donna Zanetto for allowing us to present their home in this book. To Jim for his drawings and helpful suggestions.
Thanks to Malcolm Margolin for sharing the Indian tale and for contagious enthusiasm for self-publishing.
From the Mullans, a special thanks to Robert, Maria, Markie and Ernie for their friendship and support. To Robert in particular for his role in design and construction. To Hans and Dave, for their strong and careful work and their good company. To Malia, Holly, Huyana, Maya, Erica, Lara, Sydonia and Tatiana for their helping hands and spirits.

Introduction

Building underground is an exciting idea, especially for people who want their homes to be in harmony with the natural landscape, and lower heating and cooling costs as well. We appreciate the excitement generated by the idea of earth sheltered housing; it led us to build underground structures ourselves. In this book we will examine the problems and advantages of underground building, with a detailed look at four very different owner-built underground homes.

Although underground housing is the main focus of this book, we also wish to investigate our national housing dilemma and offer some clear perspectives for instituting change. The housing crisis we now face (1982) is but one part of a widely-held uncertainty about the availability of energy supplies and material goods that, until now, have provided a few of the world's people with an extravagant lifestyle. The earth lacks the resources to sustain luxury for all. Fewer than five percent of the population in this country can now afford to buy standard new housing. Clearly we are in a period of change, seeking values that will help to establish a sustainable economy.

With this purpose in mind, we are not proposing to cover standard housing with dirt, as do most current books on underground homes. Instead, we seek ways to build that are more attuned to present realities. What can be built today that will not become obsolete in the near future? There are no simple answers. We are in the throes of a great transition and the housing models we seek will emerge only with a change in public consciousness and will.

The task at hand is to build durable housing that will not burden its owner with lifetime mortgage payments and a built-in pattern of high energy consumption. New housing should express an appropriate, conservative housing ethic, one just being formulated, one more important than any particular technique, such as earth sheltering. Our interest in such an ethic will be seen throughout this book. Positive steps towards the goal of appropriate housing will involve the construction of smaller owner-built, energy-efficient structures which are compatible with local conditions and the natural world and make the best use of site-generated and recycled building materials.

Owner-building. Owner-building has innumerable benefits; the most obvious one is lower labor cost. House building is time-consuming, but in this age of increased life expectancy, many of us will have the opportunity to build. Owner-built house design will reflect the habits and patterns of those who first occupy the structure, yet be flexible enough for use by others or future generations. A Pattern Language by Christopher Alexander et al is a helpful book detailing how cultural habits relate to housing styles and community patterns. A home may be owner-built incrementally as finances and skill allow. But building a house is not like growing a tree; everything in it begins degenerating from the day of installation. Maintenance is necessary no matter how well a house is built. Owner-builders learn from the construction experience the skills necessary to repair, replace, or remodel any part of the structures they build.

Furthermore, the owner-builder has a free choice in the kinds of materials used to build the house, while commercial builders must use highly processed and manufactured materials geared to reduce labor costs. The commercial builder can seldom use site-available materials, such as poles, soil, stone, sand, wood, etc., while the owner-builder can reap significant savings with the use of such materials.

Energy Efficiency. Energy efficiency for single family dwellings has been eagerly sought and widely studied in recent years, since homes consume 25 percent of our national energy budget. The owner-builder can give personal attention to details ensuring minimum energy consumption, as documented in the homes described in this book. Energy efficient house design begins with conservation. Living space must be well insulated. Windows, doors, vents, and chimneys have to be sealed against air infiltration. Double glazing, storm windows, and movable insulation are also effective devices. Overemphasis on conservation techniques, on the other hand, led to the design of the "superinsulated house." With double walls and few windows, little outside air infiltrates these houses. Only two air changes per day are allowed. Serious questions arise about the effects this has on human health. Should we be so exclusive of the natural world? What concentrations of noxious particles and gases can concentrate in this kind of closed off environment? New homes must conserve energy without jeopardizing human health.

The second step toward energy efficiency involves

use of the sun's heat. All new housing should use solar power to modify household climate and heat domestic hot water. There is often little additional cost incurred by using a solar design. As shown in this book, underground houses benefit from designs that incorporate passive solar gain, greenhouses, and solar domestic hot water systems.

Earth sheltering can greatly increase home energy efficiency. The low profile of these structures creates little wind resistance. Pressure differentials that cause air infiltration are avoided. The encompassing mass of earth acts as a thermal blanket, protecting the house from extremes of air temperature. Earth sheltered convective loop buildings use ground heat to modify interior temperatures.

Earth sheltered design is not without its difficulties. Increased structural loading may require heavier timbers, greater amounts of building materials, and more labor than conventional homes. Waterproofing becomes a challenge and repair may be difficult. Patterns of drainage around the house become important.

Small Housing. Of all strategies for creating energy-efficient housing, the one most often ignored is the size of a house. To save on materials and energy costs and to assume our moral responsibility for the environment, we should make the conscious choice to shelter ourselves simply with "enough, not more." By reducing space requirements, our ingenuity is challenged as well as our commitment to patience, love, and understanding of those with whom we choose to live. Houses, like cars, will of necessity become smaller and more efficient, and we will hardly notice losing the extravagance of unused space.

Design Compatible with Local Conditions and Nature Housing requires regional adaptations to function well. Solar architecture is an example of this, since solar incidence changes with latitutde and local climate. Humidity, wind directions, and subtle seasonal variations at each house site take on increasing importance as cheap fossil fuels disappear from the marketplace and natural means for achieving human comfort are sought. Housing designs of the future will reflect a diversity of microclimates. Earth shelters need even closer attention to regional and site specific conditions. The purposes and techniques for building an earth sheltered house in Minnesota are quite different from those in Arizona, and the designs for one of these locations will be inappropriate to the other.

For this reason, designs found in popular underground house "wish books" are only designer fantasies. They are a disservice to the owner-builder truly interested in innovative, locally appropriate, personalized housing. Few books with regional focus are available; Earth Integrated Architecture for the Southwest is one such text. The catalog shopping approach to underground building will rarely produce satisfactory results.

Architecture must also become more respectful of and responsive to the natural landscape. A finely designed and built underground structure inherently preserves living systems on exterior walls and roof. Perhaps our new aesthetic sense will value most a home that all but disappears amid outdoor greenery.

Recycled Materials. Our society has created an over-abundance of goods, leaving many opportunities to use surplus materials and unwanted items. The demolition of existing structures and salvage becomes increasingly important as resources dwindle and energy-efficient space becomes a real necessity. Recycling saves energy, reduces air pollution, and lessens the pressures of inflation. The advantages for the recycler are reduced costs and the satisfaction of salvaging materials, some of them so unique and precious they could not otherwise be reasonably purchased.

Site-generated Materials. In the energy equation, we are just beginning to realize the costs of transportation, such as building and maintaining roads and highways, environmental damage, medical costs from phenomenon like "Los Angeles lung," erosion, reforestation made necessary by defoliation, and the ever rising costs for fossil fuels. To build with site-generated materials takes time, but for the owner-builder this is time invested in your own place, in the land on which you live. Stone and sand for masonry, soil for brick, and building timbers may all be harvested from a home site with little negative impact on the environment and with little cost. In some instances, the land may actually be enhanced for agricultural use and aesthetic value by such gleaning measures. Raw materials need not be mined from afar and transported long distances to building sites. A structure of local material, designed specifically for its site, can quite literally look as if it had not been built but had grown in place.

Some or all of these considerations led each of us to experiment with earth sheltered design and construction. Simply covering a house with dirt and giving it

a pleasant appearance does not satisfy current housing needs. We authors have few illusions about the scale of the undertaking: to build enduring, efficient shelter for a self-sustaining society is a monumental task. We hope that the small structures examined in this book will contribute in some part to the necessary large scale solutions.

Our inspiration to this end has been the work of Baldasare Forestiere. For forty years, this lone man labored to create an underground house and garden from seven acres of land. One person can, indeed, make a difference! We begin this account by examining his work.

Chapter 1

Baldasare Forestiere's Underground Garden

Housing for humans should be strong, healthful, inexpensive, and beautiful. It rarely is. One man's creation---the underground shelter of Baldasare Forestiere---is a perennial inspiration for our efforts to this end.

During the last several decades of a lifetime that spanned from 1879-1946, Forestiere chiseled from unpromising land a subterranean environment for himself, fruit trees, and vines. Using only his hands and a pickax, shovel, and wheelbarrow, he invested time, perseverance, and hard work to realize his dream. In the process, he created an intriguing architectural paradigm for modern times: a strong, easy to build, low cost underground habitat suitable for plants and people. To this day, his structure remains entirely functional, environmentally harmonious, and incomparably beautiful.

Beginnings of an Idea. Forestiere was born in the populous port city of Messina, Sicily, near Anapo Valley, site of an extensive network of catacombs excavated over 3,000 years ago from cliffs high above the valley floor. During the Middle Ages, the tombs were converted into multi-storied dwellings. Baldasare, a child of insatiable wanderlust, was likely familiar with these diggings. From his parents, who were prosperous orchardists, the boy learned early in life the art of tree and vine propagation. With these elements firmly implanted in his background, he would one day adapt food crops and his own lifestyle to a subterranean environment.

According to custom, Forestiere, as the second eldest son, could not inherit family land. Partly for this reason, as a young man he came to this country seeking to own land and find freedom. An immigrant unable to speak English, he was forced to do manual labor at low wages for long hours. He soon learned that money was not to be made working for other

FIGURE 1.1 Anapo Valley catacombs showing typical dwelling unit.

people. Before he left the east coast, however, he was employed for several years as a sandhog digging tunnels beneath the city of Boston. He also worked on the subway tubes under the East River in New York. The experiences prepared him for a lifework yet to be revealed.

The urge to own land and nurture citrus trees and grape vines, as he had in the land of his birth, remained a dominant purpose for Baldasare. At about age twenty-five, he joined a brother living in Fresno, California, which was then rapidly becoming the capitol of fruit and grape production in this country. There, Forestiere invested all of his savings, most of which were earned working 16-18 hours a day as a farm hand, in 70 acres of undeveloped land north of the city. Assured by the salesman of the land's agricultural potential, he began to plant and build.

Site Conditions. Not far beneath the surface of his $10-an-acre land, however, Baldasare encountered an impervious stone-like layer of clay soil, called hardpan. In places it was many feet thick, preventing tender roots from penetrating to proper depths. Even today, farmers and orchardists throughout the now-famous San Joaquin Valley resort to the use of dynamite and heavy equipment to break up this impenetrable layer of earth.

No stranger to hard work, Forestiere turned this liability into an asset, persistently breaking out the layer of stony material. Beneath lay loamy soil, quite suitable for plant production. One day as he excavated for a cellar, he wondered if trees and vines would grow to advantage at that depth, perhaps enjoying an extended growing season free of winter frosts. By the same token, would blistering summer temperatures be modified for him by the natural coolness of the deeper layers of earth? He recalled his experience in tunnels where, with adequate ventilation, air temperature would remain a constant 58 degrees Fahrenheit at depths of 10 feet and below. Summertime temperatures throughout the valley fluctuated between 80 and 120 degrees. Without modern mechanized air conditioning, valley residents of yesteryear sweltered in above ground frame housing. It was probably this fact that persuaded Forestiere to build and live underground himself, among his flourishing plants. The germ of an idea was planted, and the Underground Gardens began to take form.

Subterranean Shelter. Baldasare picked at the hardpan until it broke loose in large chunks. These he formed into manageable shapes that he laid up to form walls and vaulted ceilings. As he built upward, he tamped loose soil in the space between his structure and the excavation. In this manner, by 1924 he had built 65 underground enclosures, many of them open to

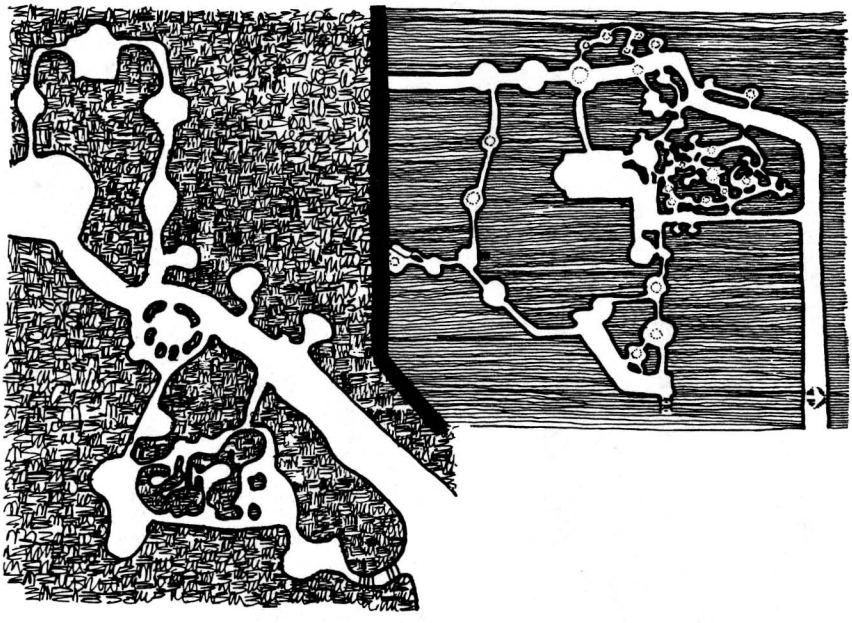


FIGURE 1.2 Underground gardens plan (right) and apartment area enlarged (left).

the sky at their apex. They varied in depth from 10 to 25 feet below ground. When all galleries and patios are included in the count, there are nearly 100 such constructions, connected by passageways, that course through 7 acres of land.

In patios and galleries, he set out fruit trees and vines in planters measuring from a few feet in diameter to 18 feet across. Some receptacles lay beneath skylights formed in domed ceilings. Through these openings, plants reaching ever upward received light throughout the day as the sun moved across the sky. Rain irrigated the planters in season. Several dry wells were dug to govern any excess run-off of water. For himself he built a four-room hobbit-like apartment. During the winter, Baldasare placed flat pieces of window glass over the skylights to hold warm air in his apartment, which he heated in cold weather with a small wood fire.

For his efforts, Forestiere was doubly rewarded. Not only had he solved the hardpan problem for his plants but he had made appropriate housing for himself. Surely, on many occasions during his lifetime,

FIGURE 1.3 Baldasare beneath grape arbor. Note overhanging grapes.

he reveled in his creation which held many delights for him. When strolling beneath a massive wooden arbor covering the long, elegant entryway, visitors could in season reach up and pluck five varieties of delicious grapes for their pleasure. Natural light spilled down through skylights and courtyards and reflected off gently curving masonry walls so that the Gardens most often appeared light and airy. Trees and vines, in galleries or courtyards, provided Baldasare with color, movement, sound, and nourishment as well as beneficent summertime shade. Live fish, caught in a nearby river, swam in a courtyard pond outside his living quarters until he chose to fetch one of them for his dinner. Here, in the same patio adjacent to his apartment, he bathed daily in a tub when the sun had sufficiently warmed water stored in an old tank above ground. Bath water was later shared with plants.

A man of great reverence for life, Baldasare built a chapel with a court yard in which he one day hoped to be married. He carved two niches from the stony earth in his apartment. In one overlooking the courtyard, he slept on a modest cot when the weather

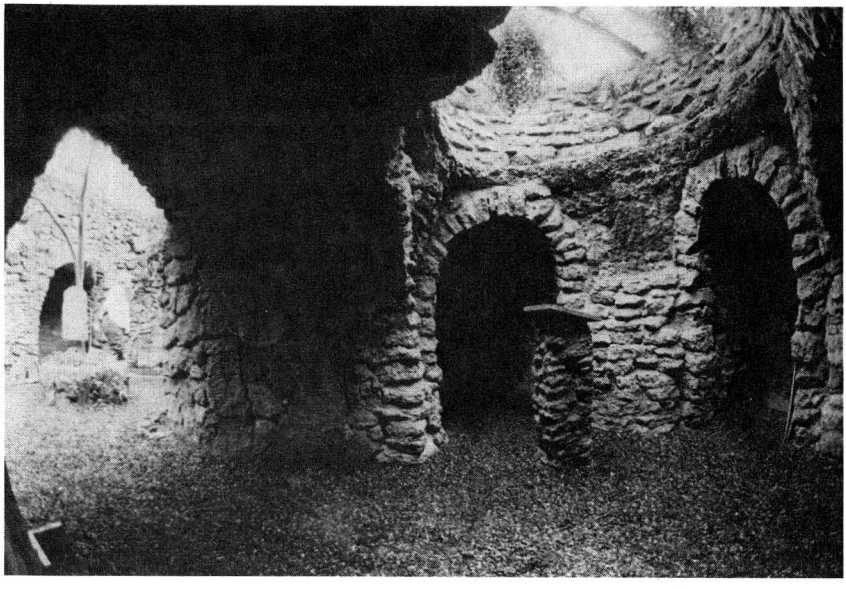


FIGURE 1.4 Chapel area and adjacent courtyard.

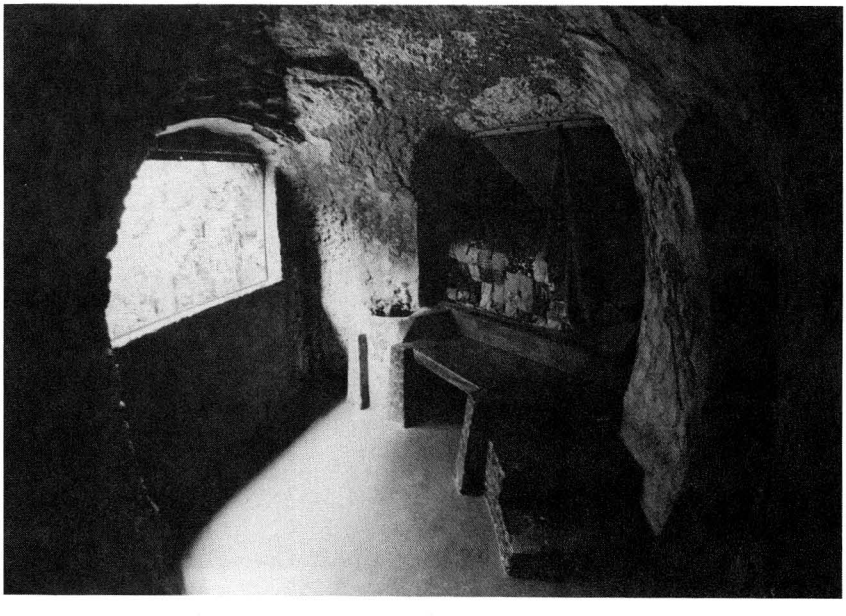


FIGURE 1.5 Sleeping alcove with courtyard exposure.

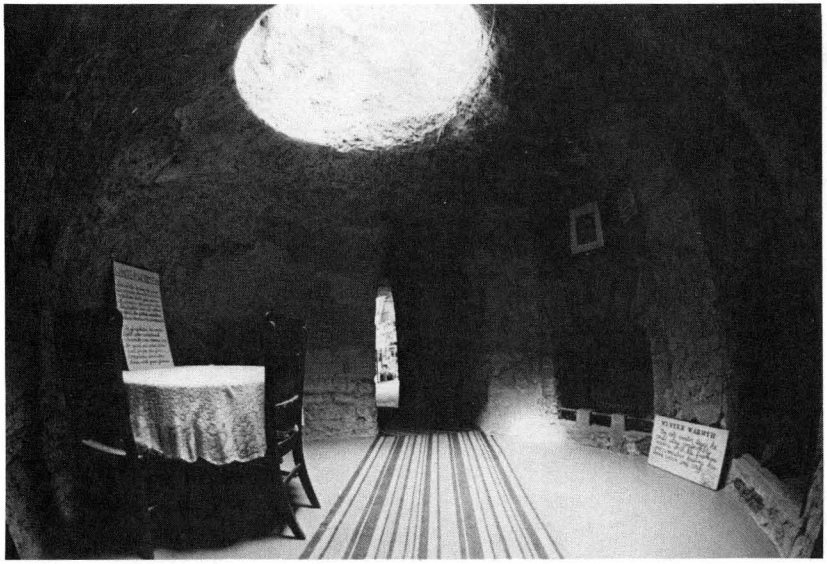


FIGURE 1.6 Living quarters.

FIGURE 1.7 Corridors leading from court yard. Note steel-wheeled barrow, Baldasare's major transport tool.

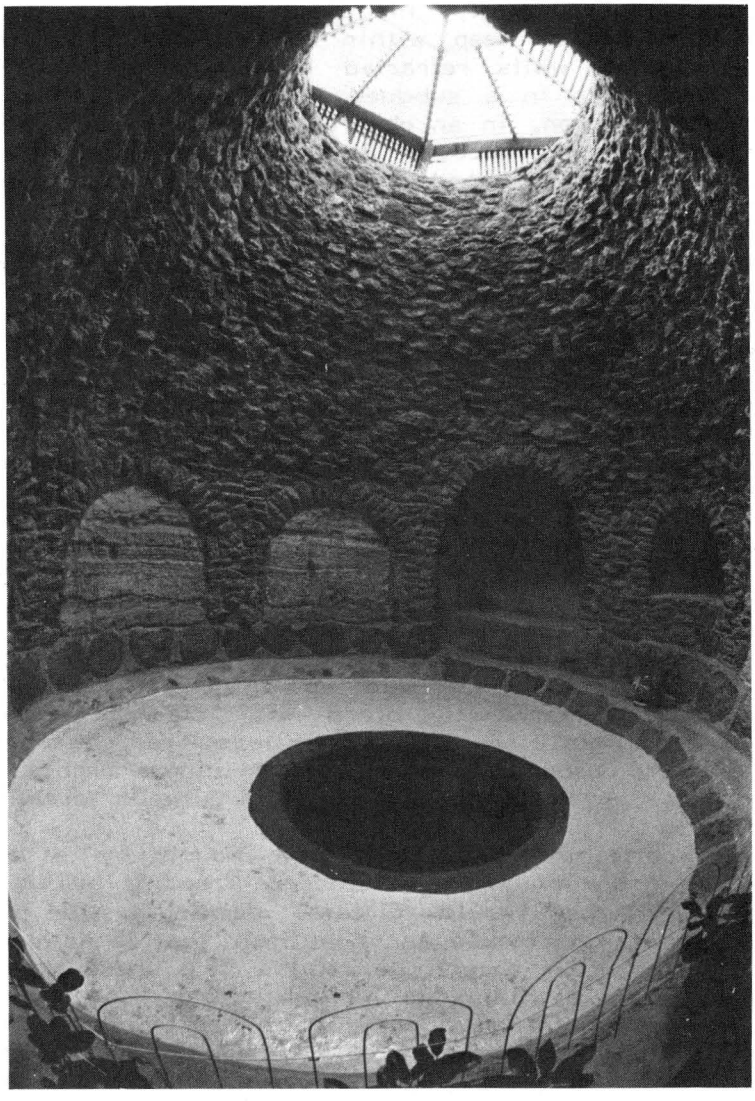


FIGURE 1.8 Aquarium room with glass bottomed pool for observation from lower room.

was mild. When it was too hot or too cold, he slept in an inner recess, protected from the elements. A man who loved beauty, his piece de resistance was an aquarium grotto, deep within the caverns. Its generous, sloping walls refracted incoming light, bathing the atmosphere in a subdued luminescence. On many a summer afternoon, in an observatory lounge built directly beneath this alcove, Baldasare would relax and watch through the pond's glass bottom as fish swirled serenely overhead.

The subterranean environment was ideal for exotic tree crops as well. These included a strawberry tree, pomegranates, Chinese dates, mulberries, and many varieties of citrus. One tree, expertly grafted, bore seven kinds of fruit: grapefruit, sweet lemons and sour lemons, navel and valencia oranges, tangerines, and cedro, a type of citrus. It still bears today, fifty or more years after its planting. In his care, free of horticultural prescriptions, the most delicate varieties thrived.

Structural Sensibility. Despite a lack of formal education, Forestiere worked skillfully with technical concepts. Seemingly unaware of limits, he engineered free-form earthworks---curving walls, archways, barrel vaults, and domical roofs---each of them among the strongest structures known. All are built with blocks of hardpan, sometimes laid up without mortar while some are mortared in place with clay or cement. Discarded metal of all descriptions---rod, bedrails, wire---were used to support and reinforce arches and skylights. A drainage system of dry wells preserved his work.

Architecture had long been bound by straight lines and abrupt angles. Baldasare freed it by sculpting as whimsy would dictate, declaring that, "To make something crooked and beautiful, that is a wonderful thing." Even though he read a lot, there were no how-to books available to him about the kind of work he was doing. Asked about the desirability of working from plans, he remarked that they would encumber him. "Every time I'd turn a corner," he would say, "I'd have to check a little piece of paper to see if it was the right corner to turn!"

Subsurface Ventilation. Equally functional and impressive in concept and performance as the structural integrity of his work, is Forestiere's use of natural ventilation and temperature regulation in the Gardens. Air movement through this subterranean labyrinth was

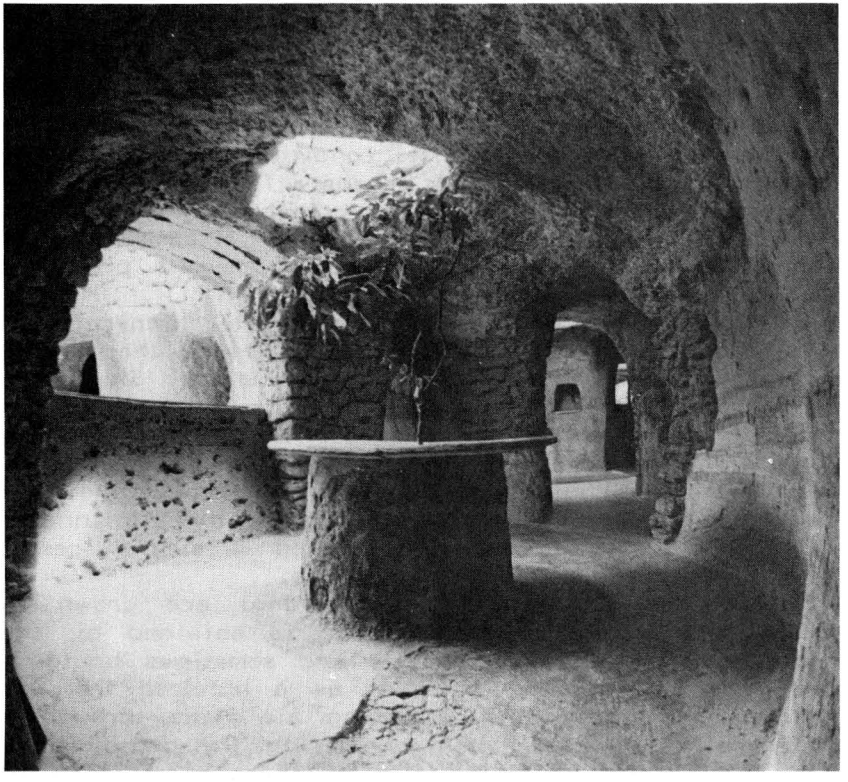


FIGURE 1.9 Unplanned curvilinear garden room.

carefully planned and laid out. Without continual air movement for an equitable exchange of air, the underground environment would have become oppressive and unhealthy. The challenge was to induce cool, fresh air to enter down into his buried chambers where it would circulate, heat, and exhaust above ground.

As a former tunnel worker, Baldasare undoubtedly knew of the need for adequate air conditioning below ground. He may have known, too, of the instinctive preparations for ventilation made by animals and insects that live in earth-enclosed mounds or in underground burrows. To conserve body temperature, derived by the expenditure of valuable chemical energy, these creatures harness a free form of mechanical energy, caused by differences in air temperature and pressure, to move air. Forestiere accomplished the same result for himself, creating a comfortable, refreshing microclimate. Paradoxically, this remains an elusive goal

for San Joaquin Vally residents, who today achieve "climate control" with high priced air conditioners and large amounts of electricity.

Mound Ventilation. Without need for the capital outlay and the energy we invest to acclimatize our homes, the African termite conditions its cavernous nesting place by natural means. To survive, these creatures create and maintain a favorable environment while also contending with the harsh circumstances of their surroundings, which include numerous predators and severe climate extremes.

To achieve high humidity, stable temperatures, and adequate air flow, the earth walls of the termite mound are built tall and conical in shape. Since this form has less surface-to-volume ratio, there is less interior space to cool or to heat. In other words, the termite mound presents the least surface area to a sometimes unfriendly exterior environment for the volume of interior living space enjoyed by its inhabitants. Baldasare Forestiere achieved a similar result with his curved, domed living spaces.

To nourish termite brood, fungi are grown in moist underground gardens. Water is obtained by the insect's tunneling down for it and sometimes bringing it up from depths of as much as a hundred feet. At the base of the mound, incoming air flows through a water-saturated tunnel before entering the brood chamber and fungus gardens. It exits through openings in the top of the mound. Due to the substantial difference in height between the air inlet and the exhaust outlet, a chimney stack effect is created, which pulls air and moisture through the darkened recesses of the termite mound, from bottom to top.

Termites breathe through their skin, taking in oxygen and releasing carbon dioxide. Therefore, it is imperative that they receive a continual supply of fresh air in their earth-enshrouded world. Since they live most of their lives surrounded by earthworks, oxygen and carbon dioxide must be exchanged through the thick walls of the nest as well as through holes in the top of the mound.

The chimney-like nests of the African termite sometimes reach sixteen feet in height in a shape that induces upward air flow. The attic area of the mound collects carbon dioxide exuded by the insects enmassed within. Here, through "lungs," the convoluted outer walls of the mound, this waste product is exchanged for fresh sources of oxygenated outside air. Both of

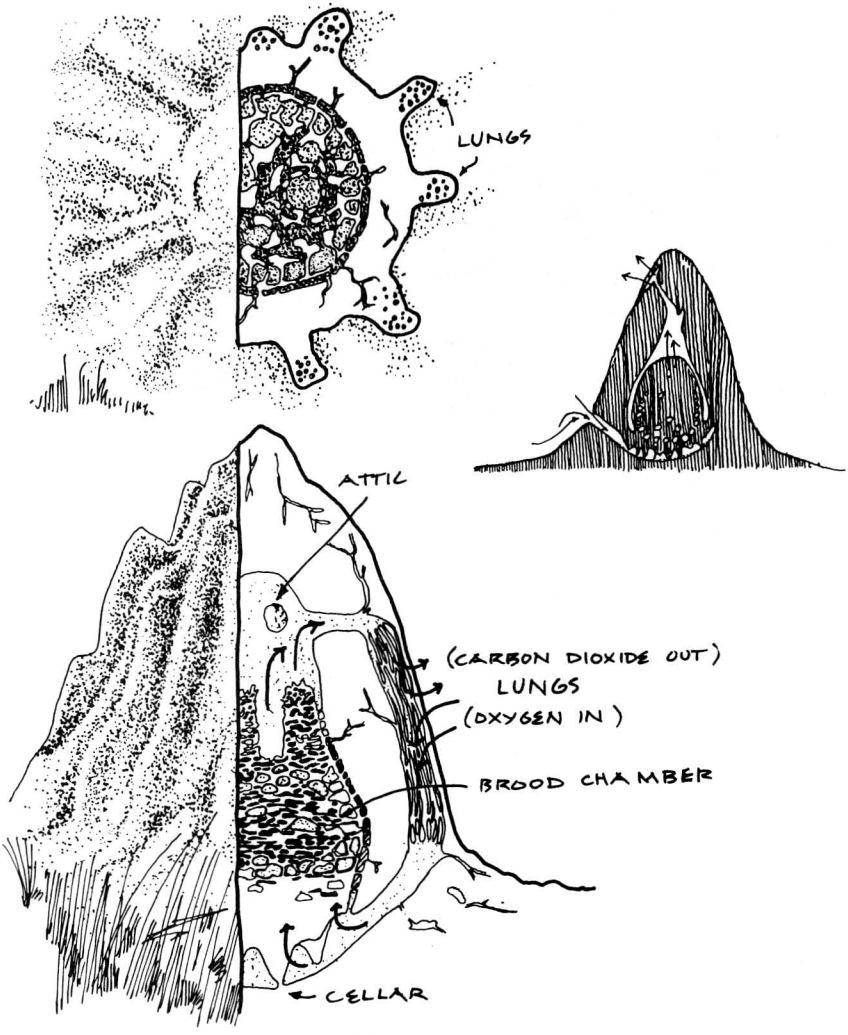


FIGURE 1.10 Termite mound ventilation.

these gases pass either into or out of the mound through these earthen walls because of the difference between outside and inside air pressure.

Burrow Ventilation. Forestiere's meandering subsurface maze required a horizontal flow of ventilation, similar to that used by the prairie dog, which burrows beneath the flat lands of the Great Plains of North America. In well compacted soil, this animal may

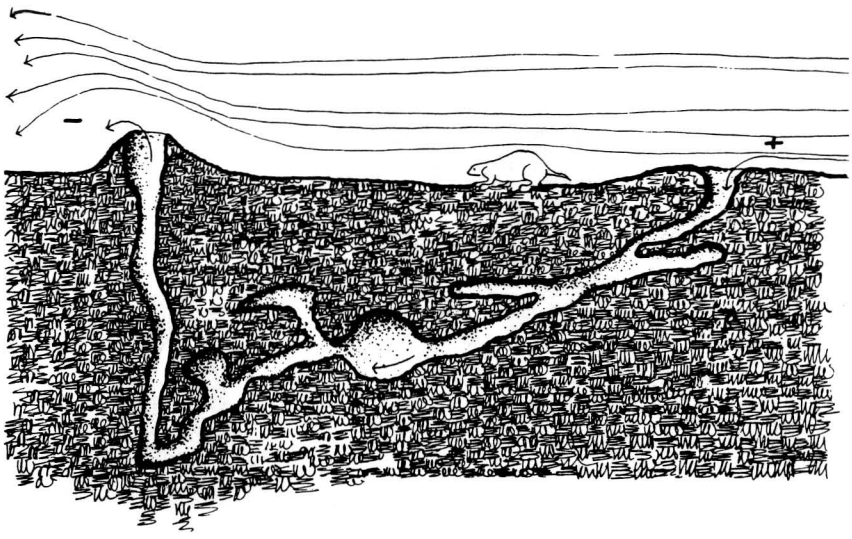


FIGURE 1.11 Prairie dog burrow ventilation.

tunnel to levels ten feet deep, digging shafts as much as fifty feet long. At these depths, since convective air currents are inoperative, fresh sources of oxygen would seem unavailable to animals living there. Yet in its deepest burrows, the prairie dog enjoys a complete change of air every ten minutes, even when outside air is motionless. It digs two separate openings at opposite ends of its burrow. One is a slight scoop-shaped opening in the surface of the ground, while the other is a funnel-like opening in a crater of soil piled high above ground. Air pressure at the lower of these two entrances is less than that at the more elevated one. This difference in air pressure creates a drawing or suction action, moving air through the length and depth of the burrow.

Differences in the size and shape of these entryways also contribute to the pressure differences that move air along this critter's tube ways and through its secluded cells. Air is scooped up in the more generous concave entrance hole, drawn downward by a difference in air pressure (high) at the other end and forced out of the taller but narrower crater-like opening of the prairie dog tunnel.

Ventilation and Temperature Regulation at the Gardens. These two phenomena, the stack effect (of the termite mound) and air pressure differential (in

the prairie dog burrow), operate to ventilate and regulate the temperature of Baldasare Forestiere's underground digs. His system of natural ventilation required neither expensive engineering to lay out nor energy-consuming machinery to force air circulation through the winding corridors. Fresh air for this labyrinth of chambers and gallerys begins its downward flow along a generous outstretched ramp that opens in the direction of the prevailing summer breeze. (It opens opposite that of the prevailing winter storm track.) Vines cover an expansive arbor covering this entrance way, shading the area so that incoming air cools naturally beneath the leafy vegetation and in contact with the moist earth.

FIGURE 1.12 North-facing entryway is source of fresh air ventilation.

Farther in the Gardens, Forestiere's tree-growing galleries with their funnel-like openings to the sky, function as do the cratered exit of the prairie dog burrow, removing air efficiently from the subterranean network. As air wafts along underground passageways in contact with the surrounding earth, it is tempered and moistened. Summer and winter, the Garden's atmosphere tends to stabilize at earth's constant temperature. One recent summer day, while valley residents sweltered in 110-degree heat, air temperature in the observatory (25 feet below ground) beneath Baldasare's

glass-bottomed fish pond registered 79 degrees, a difference of 31 degrees! Air, warmed as it passes over sunbaked masonry, also rises and creates a turbulence that keeps it mixing and ever moving throughout the Gardens.

An Assessment of the Legacy of Baldasare Forestiere. Today's visitor to the Forestiere Underground Gardens is often heard to exclaim, "What a lot of work!" Without doubt, through the years this master owner-builder, using only hand tools, did exert phenomenal effort to excavate and re-lay many tons of rock to build subterranean shelter for himself and his trees and vines. Yet, upon reflection, there is more to be unearthed in the Gardens than this fact alone. What did inspire the extraordinary labors of this diminutive man who barely weighed 100 pounds? Surely, there were rewards less tangible though equally gratifying than unrelenting hard work and the simple acquisition of shelter alone.

The Garden's attraction resides in part in its creator's abiding regard for the value of personal industry. Through persistent devotion to physical labor, Baldasare achieved great personal freedom and

FIGURE 1.13 The basic hand tools used by Baldasare to build his gardens.

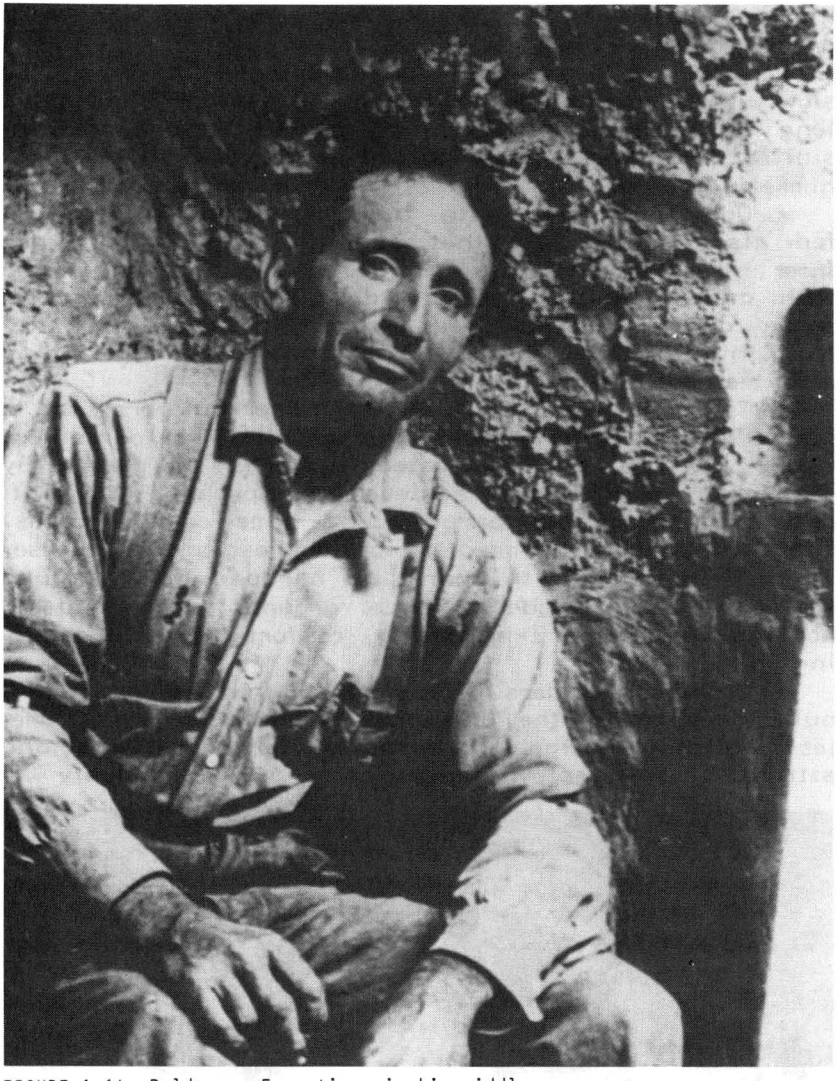


FIGURE 1.14 Baldasare Forestiere in his middle years.

self expression. These, in turn, gave him a sense of self, of his being, and brought meaning and direction to his life. His dedication to self-directed work speaks particularly to those owner-builders intent on building their own homes today, for in discipline to the task lies the path to true freedom and artistic expression. This fact is as important as the magnitude of Baldasare's physical feats and his spectacular achievements.

His work attitude, on which his endurance and work accomplishments hinged, is summed up in a modest expression he was fond of uttering: Va sano (Go slowly), va piano (go softly), e va lontano (and go a long way). Unwaveringly, he accepted personal responsibility for the completion of any task he set for himself.

Our fascination with this man and his work is fed also by the fact that everything he built flowed from his own personal committment to a life shared with growing things. His building solutions reflect his sense of interconnectedness with the forces of life, with things of the earth. His is truly a life-sustaining architecture.

The challenge for us as owner-builders is to create similar life-reinforcing constructs for ourselves, using our own self-motivated patterns of work. By examining this man's achievement, perhaps we will glimpse some of his purpose and some of his means. Then, whatever the medium of expression we choose, whether we build with chunks of hardpan below ground or with wood members above ground, the resulting housing will be as exhilirating, comfortable, and enduring as this man's.

Timeless Builders. The work of this master owner-builder expresses the universal characteristics of timeless building design, construction, work patterns and attitudes. To employ these tools, we have only to

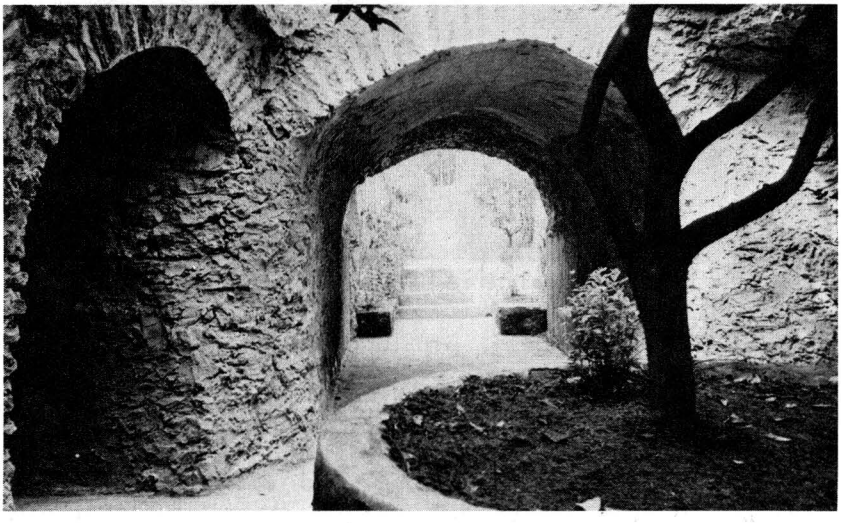


FIGURE 1.15 Light and airy garden rooms.

project ourselves into the mind set of the builder who realized goals we also seek. In his example, there is an enormous source of energy and inspiration that may be tapped by others. Throughout our building careers, we authors have often found this special reservoir of energy and creativeness in the work of owner-builders. This same energy we perceive in the underground gardens of Baldasare Forestiere. A face-to-face interview with its creator is unnecessary for us to recognize and understand his goals and to use his means for achieving them, for they are clearly stated in enduring architectural form. Carved from nature as they are, the Gardens is a record of part of this man's life.

Builders who achieve a similar timeless quality in their work often exhibit a number of traits in common. They begin work by visualizing their goal and a means for achieving it, while they remain open to the possibility of other imaginative solutions along the way. They master their craft and use it to a high degree, yet remain free to experiment with other tools and techniques they discover. They apply themselves to the task at hand, their aesthetic achievement being an out-growth of self-discipline. The investment in time is a matter for subjective interpretation only. Finished structures meet all requirements, and job satisfaction runs high; these builders enjoy their experience. A discussion of these points follows.

Like other builders of timeless architecture, Baldasare literally "broke ground," envisioning an unusual housing form and ways to accomplish it. Most of his building precepts were without local precedent. The building designers of his day, like those now, merely reshuffled prescribed architectural components in hopes of creating structures that would be acceptably fashionable. Baldasare, on the other hand, surrendered himself to an organic and visionary building process in which design and technique were revealed to him at all hours of the day and night throughout the years.

Before the first chunks of hardpan were laid, Forestiere contemplated conditions in which his trees and vines might thrive better than those imposed on them by the stony soil of his site, a searing summer climate, and killing winter frosts. Giving free range to his imagination, Baldasare explored various solutions to the site and environmental conditions he encountered. What evolved was shelter appropriate to the needs of his plants as well as to himself.

Drawing from work experience gained as a youth and as a young man, Forestiere built stone archways and tunnels that successfully bore the weight of many tons of earth lying above them. His vaulted domes are examples of the most appropriate use of stone as a building material, each piece an integral part of the sturctural whole.

By experimentation, a builder not only discovers the best possible use for building materials but finds that they, in turn, govern one's use of appropriate tools for the job. Baldasare devised a pre-built form with which he cast circuitous arched passageways. Whatever tools or techniques are employed by a builder, they must be appropriate to the conditions and the tasks at hand.

Nowhere in the Gardens was the opportunity for aesthetic expression overlooked by this timeless builder. As work progressed, Forestiere developed interest and variety at every turn and at every level of his earthworks. Frugally, he used left-over cement to repair and decorate his work. He trimmed planters in his light wells with pebbles from the river and formed a drip ledge above windows opening into the courtyards. From these sills, shadows sculpt an added dimension to the flat plane of the opening. Raindrops form beaded patterns of liquid silver for the observer's intrigue as they fall from this sill. Nature itself resides here, clinging to the earthen walls of patios, adorning at random with mosses and delicate native plants carried there by wind and birds.

Nowhere in the Gardens does one detect the monotony of slick surfaces and ordered symmetry so often encountered in the architecture of today. Here, Baldasare masterfully provided slight variations, even distortions, to relieve the eye and stimulate the senses. Wherever the visitor walks in the Gardens today, there is always some vista beyond that beckons exploration. One is compelled by curiosity to continue on into a new patio or along yet another passageway. Baldasare would awaken during the night with a vision of some new creation just revealed to him, his whole being in awe of the experience.

Today, the Gardens, though in some disrepair, remains lush despite its creator's absence. These premises, when Forestiere was alive, provided him with a vitality still apparent in the carved forms and the flora, still living, that was once tended by his hands. There are few better examples of so integrated

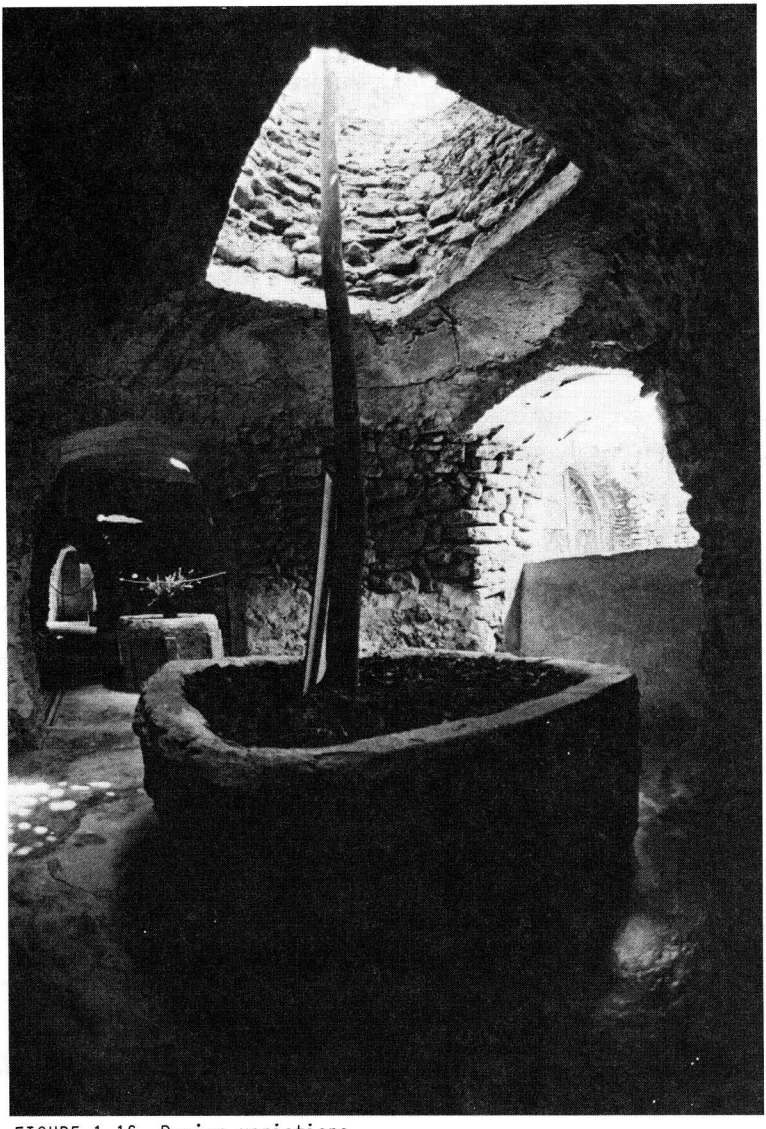


FIGURE 1.16 Design variations.

a complex of shelter and gardens. The mingling of architecture and growing plants makes it difficult to perceive where form ends and growth begins.

Sustained physically and spiritually by his work, Baldasare received an inexhaustible supply of energy to support his efforts. Otherwise, he could not have survived the years of arduous labor required to build this extensive network of sunken patios and rooms. His investment of money for his 7 acre project was insignificant: a few hundred dollars for cement. The pay-back in personal satisfaction, however, was obviously great, for Forestiere never questioned the length of time necessary to do a righteous job; he willingly invested forty years of his life. By contrast, today's average homeowner purchases instant housing and then spends forty years as a wage slave to pay for someone else's work.

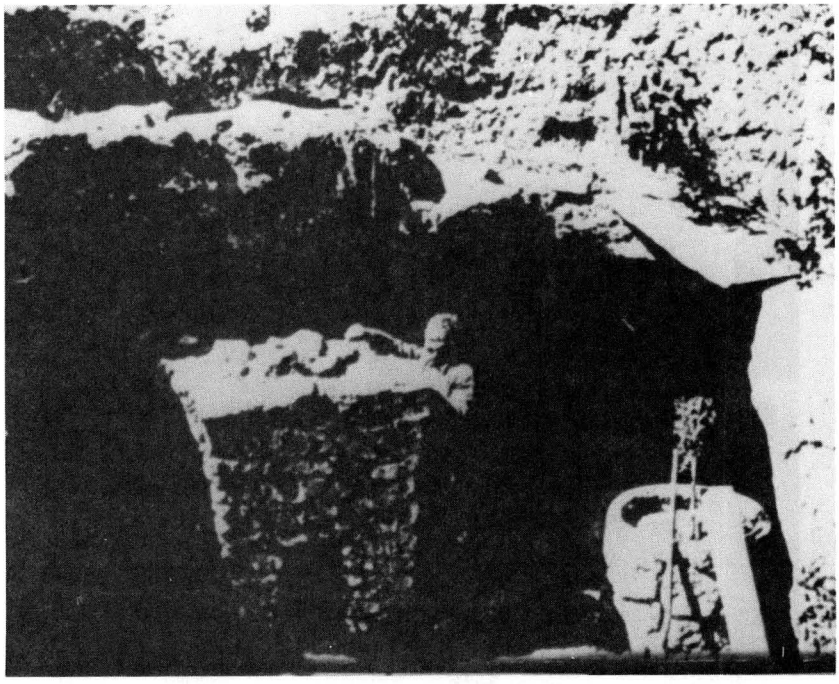


FIGURE 1.17 Forestiere in his later years at work.

The success of any endeavor depends on how well the job is executed. One striking thing about the underground habitat of Baldasare Forestiere is the harmonious relationship of the many different architectural elements of his work. His building system, which

he used repeatedly nevertheless allowed for wide variation in proportion, style, rhythm, and nuance. Still, there was enough consistency to maintain the Garden's architectural integrity.

Creating architecture in this way can be an intensely interesting and enjoyable experience. Baldasare's work was "fun" for him. Were it otherwise, he would have ceased his efforts long before forty years had passed.

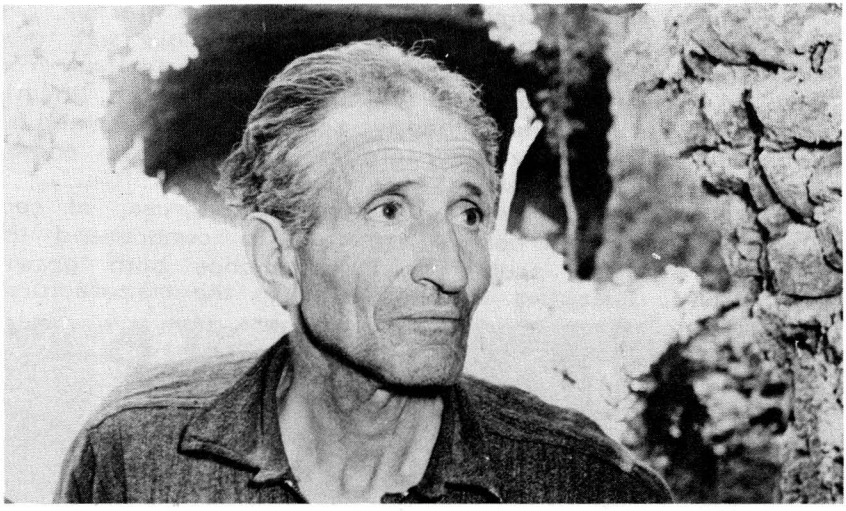


FIGURE 1.18 Baldasare at rest.

Freedom to Build. The Underground Gardens is a living testament to the freedom to be and the freedom to build, a concept energetically espoused by the contemporary Austrian artist, Friedrich Hundertwasser. He feels, as we do, that people everywhere should have the opportunity to express themselves in the building of their own homes. Hundertwasser's view of appropriate housing, like Baldasare's, cannot be found in the rigid prescriptions of uniform building codes. He declares that professional designers, contractors, and building officials are wrong to interfere with the legitimate work of owner-builders, that habitable architecture is the sacred preserve of the tenant, who must assume responsibility for its creation. Policing action to maintain conformity to other's standards, he feels, is an injustice. Baldasare lived in a time in which

he was free to excel both as a builder and as an orchardist. In the Gardens on his own land, life was unrestricted by custom, convention, or law. Creative building design sprang from his own innate sensibilities and from the opportunity to experiment for himself, not from the imposition of arbitrary codes. Few builders today have the opportunity to commit themselves to a project of their own choosing and formulation as Forestiere did.

Freedom to build even means an occasional wall or roof collapse which, Hundertwasser maintains, can have a positive result for the builder. This was true also for Baldasare. He made some miscalculations from time to time but found philosophic consolation in his mistakes, calling them "happy accidents predestined to be made better." By embracing his errors, he encompassed that wholesomeness which characterizes life.

Life is an interplay of opposing forces, of constructive and destructive aspects. To comprehend the fullness of life, people must experience both growth and decay. Speaking in opposition to the manufactured

FIGURE 1.19 Forestiere's trinity courtyard---beauty, goodness and truth.

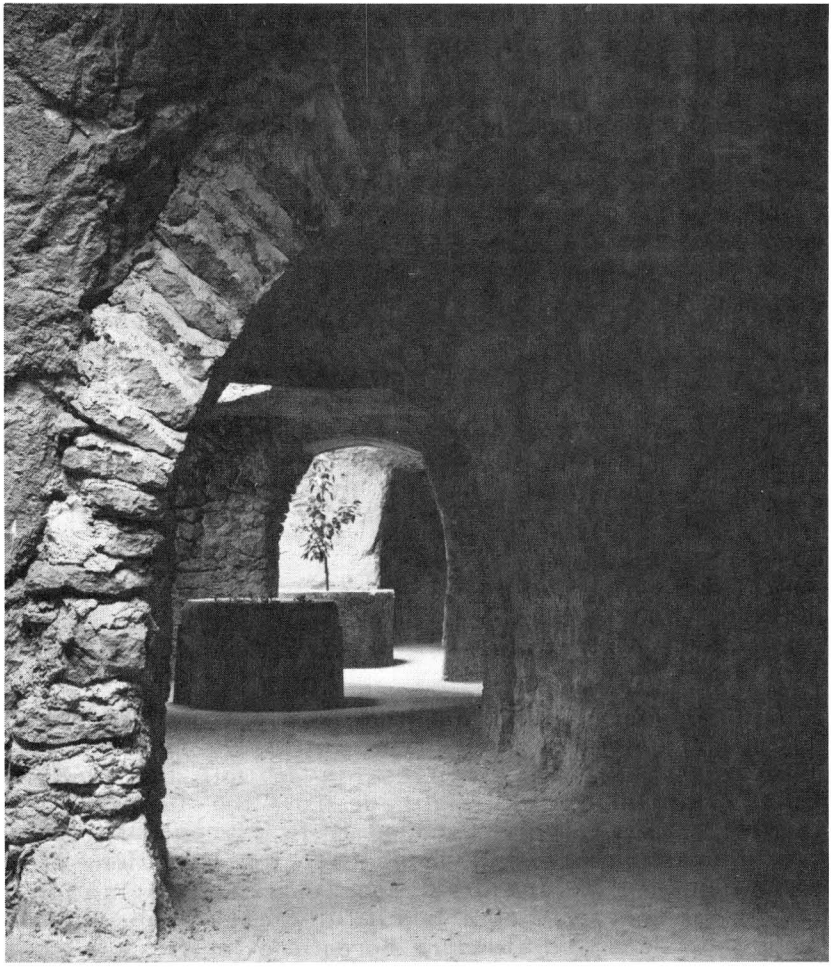
sterility of rational, functional architecture, Hundertwasser calls instead for our awareness and acceptance of the "creative moldiness" found in nature's wild and uncontrolled growth. "The swelling moldiness," he writes, "subjected to its organic law of expansion, must make structures ferment and smash the straight line in building!" The oppressive dictates of today's "criminally sterile" architecture will otherwise rob us of our humanity, he warns, leaving us with but a facsimile of life.

Baldasare Forestiere lived intimately with alive and growing things, with the changing of the seasons, the comings and goings of small birds and wild creatures. He was immersed in the organic state of life, in the dynamics of growth and decay. The Gardens is today still a place alive and full of human richness precisely because he was free to be his own person.

Having lived in different times, Baldasare Forestiere and Friedrich Hundertwasser never met but are kindred spirits nonetheless. In the classic tradition of the European anarchist, these two men are champions of architecture for people. If Baldasare were alive today, he might well occupy a front line place in the struggle for individual freedom in building.

Epilogue. Today, not far from the Gardens, traffic speeds along a four lane interstate freeway, and there are those who, in seeking to sell the land for their financial gain, would destroy the Gardens. The complex survives only because it is courageously cared for against compelling odds by the devotion of a nephew's family. If there were ever a rallying point for the preservation of a beautiful creation, the Underground Gardens of Baldasare Forestiere is it!

FIGURE 1.20

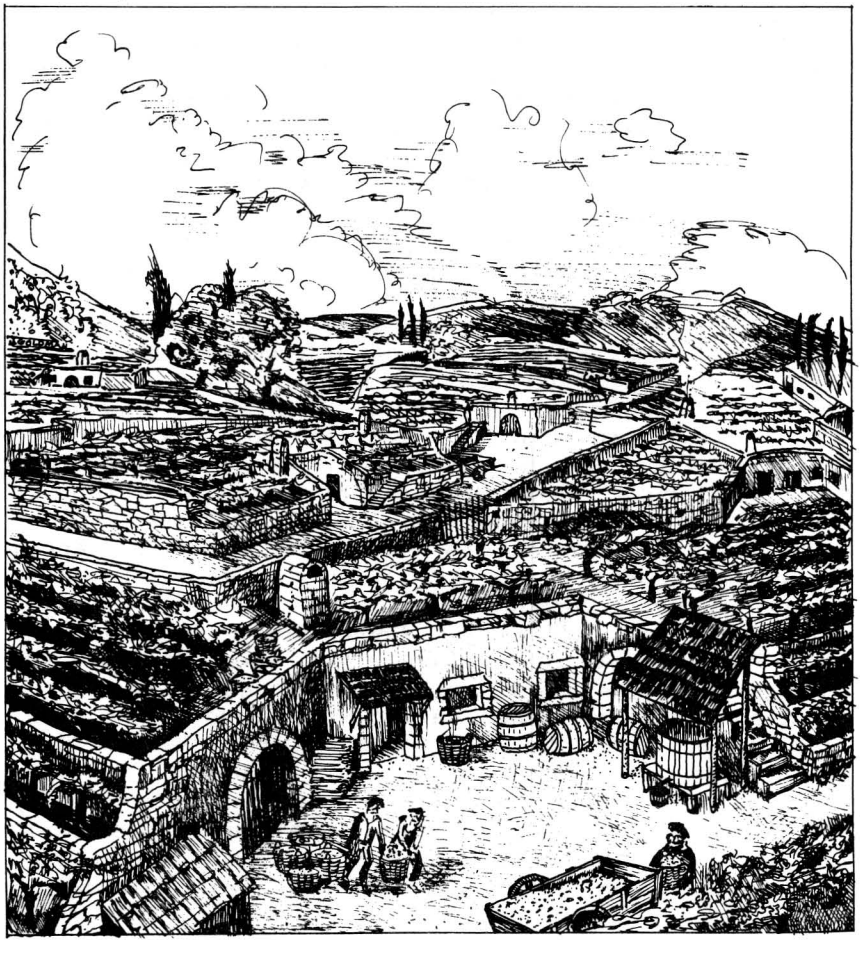


Va sano, va piano, e va lontano.

Baldasare Forestiere built only, in the words of Christopher Alexander, "on those parts of the land in the worst condition, not the best." He also practiced small-scale site repair by doggedly transporting to the surface any rich alluvial soil found beneath the hardpan of his building site. Thus, he preserved level land topside for agricultural purposes, creating lush gardens and orchards above as well as below ground.

A comparable but large-scale site repair took place earlier this century in the village of Beau la Ronce, north of Tours, France. In ruins today, this underground village was reported by S. Baring-Gould, in 1911, in his book Cliff Castles and Cave Dwellings of Europe, as follows: "There is often very valuable vineyard land that has to be walled round and every portion economized. What is done is this: the owner digs a quarry in the surface. This forms a sort of pit accessible on one side, the stone taken from this being employed to fence round his property. Then, for his own dwelling, he cuts out chambers in the rock under his vineyard, looking through windows and a door into the quarry hole. For a chimney he bores upward, and then builds round the opening a square block of masonry, out of which smoke escapes.

A whole village, or rather hamlet, may therefore consist of---as far as one can see---nothing but a series of chimneys standing on the ground among the vines. Those who desire to discover the inhabitants must descend into the quarries to the rabbit warrens."



Chapter 2
Soils

Soil and groundwater conditions determine the feasibility of building underground. While above ground site analysis is usually adequate to reveal the raw materials and general conditions for house design, building underground requires thorough top soil and subsoil study---well before any committment to subterranean building can be made.

Baldasare Forestiere lived in a typical, poorly designed farmhouse on orchard land before he began his subsurface investigations with pick and shovel. The rural-based owner-builder contemplating building underground may likely be in the same position. Often the procedure is to build a barn or shop first and live in it while exploratory excavations are made. This is recommended, for the stakes are high when building underground. An owner-builder should take time to think seriously and observe the site for drainage and soil stability.

Once a site is chosen, several means are available from which to obtain relevant information about soil conditions. The Department of Highways in your state may have information on soils taken from experience with highway construction done in your locale. This department uses the soils classification system employed by the American Association of State Highway Officials. With this system, there are seven designations for various soils, from A-1 (gravelly soil of high bearing foundation strength) to A-7 (highly plastic clay soil of poor subgrade strength).

Your local USDA Soil Conservation advisor will also likely have information about your specific soil conditions. Their maps are extensive and detailed. A conscientious real estate agent may also have them. This system uses the soil classification triangle. (see illustration and chart at end of chapter). You will want to know about their services, for as a landowner, you have paid taxes for them. The Soil Conservation Service will also have information on groundwater. The Service can refer you to local soil exploration

and testing firms, or to local consulting engineers regarding soil bearing conditions and drainage. If you are close enough to a municipality, the city engineers will be able to give you information on the bearing capacity of soil related to building foundations.

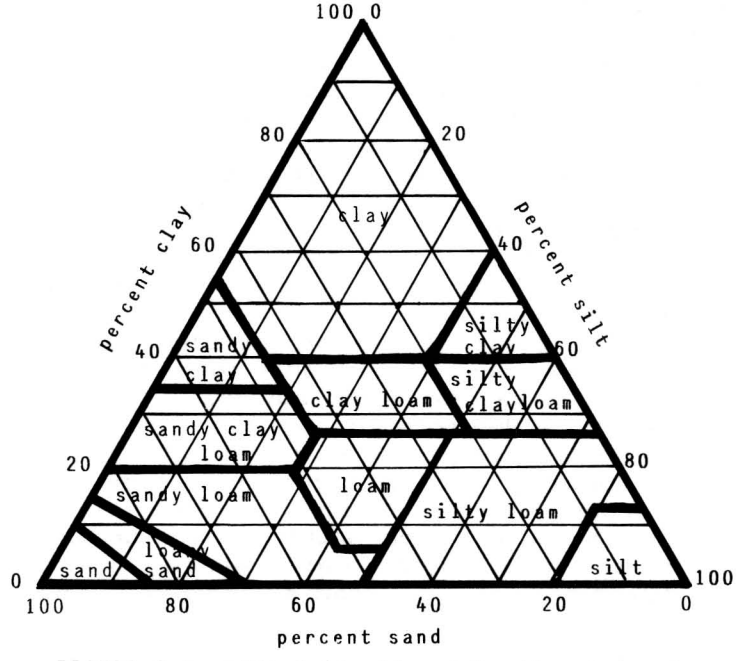


FIGURE 2.1 USDA Soils Classification Triangle.

Private engineering firms are generally helpful. Through simple telephone contact, they will usually tell you if there are soil problems in your area relating to foundations. Should there be problems, they will give you information regarding the problem to try to sell you their services. Of course, there is always the private sector huckster, but with common sense you can usually detect them before they cost you much.

While we are not soil scientists, here are some of the limitations of soil to lookout for:

Shrink-swell Potential. The Federal Housing Authority refers to this as potential volume change (PVC). Soil scientists refer to it as the coefficient of linear

extensibility (COLE). Low shrink-swell soils are sandy, loamy sand, sandy loam, loam, silty loam, or they are clay loam, silty clay, sandy clay, and clay where it has a low shrink-swell potential. An example of this latter type of clay is kaolinite. These soils are designated as PVC-1 to 4 or as COLE 0.01 to 0.05. High shrink-swell types are clay soils such as montmorillinite or bentonite. These soils range from PVC-4 to 6 or more or COLE 0.06 to 0.09 or more.

The importance of a soil's shrink-swell potential cannot be ignored. Denver area soil contains a bentonite clay that commonly buckles basement slabs, requiring special basement, partition, and stairway details, and special arrangements for roof drainage to prevent water from soaking soil within six feet of the house. Even foundation cracking is not uncommon. If you encounter soil of this type, do a lot of investigating and consider hiring some professional consultation. Arrive at the consultant's office with concise questions regarding the scope of the problem for your specific plans. Half an hour of expensive consultation may be a small price to pay for sound advice.

Plasticity. Underground building requires much earth moving. If your soil is highly plastic with lots of clay content, you will probably experience soil slumping down into your excavation after a rainstorm. Too, your carefully placed backfill could dribble downhill. In any case, local soil plasticity will be the final determiner of your soil's angle of repose, or degree of slope, which you will need to know for landscaping.

Frost Action. Frost heave is caused by freeze conditions and spring thaw. Usually in silty soil, frost penetrates to form "ice lenses," which cause lateral and upward movement of soil. With thaw, this movement collapses.

Bearing Capacity. How much loading a soil can support without deforming its structure is called its bearing capacity. An underground building will rarely require more than 3000 pounds per square foot of bearing capacity. The houses discussed in this book require much less.

Corrosion Potential. This may seem an unusual concern, but very acid soils have high concentrations of sulfate that is corrosive to concrete. This points up the fact that occasionally in this work you may encounter conditions you never before imagined possible.

Natural Phenomenon. Flooding is an obvious prob-

lem. To build an underground structure in an area of flood plain would be ridiculous. Underground houses built in the Midwest have been shown to resist damage from tornados. Earthquake is another problem. According to Earth Integrated Architecture:

> These subsurface structures are not subject to the forces that dictate the structural design of those above the surface, as outlined in the Uniform Building Code for the different seismic zones. From studies of damage caused by earthquakes, rigid structures below the surface level, such as basements, parking structures, and enclosed underground utilities, are relatively unaffected by horizontal acceleration that is damaging to above-surface construction...A rigid underground structure is not subject to the internally-induced forces of above ground structures resisting the movement of the mass caused by horizontal acceleration. It is these internally induced forces that damage above surface structures. The forces of a below surface building remain external because of its direct contact with the earth. These structures may experience the motion of vibrations of the earth because of external forces but, since there are no internal forces induced to resist this movement, there would be a minimum, if any, damage. Thus, it would appear that subsurface structures may be a better solution to earthquake resistance than above surface buildings.

"We would like to take issue with this presentation. We, Jane and Otis, living in Guatemala in 1976, were near the epicenter of an earthquake that measured 7.9 on the Richter scale. We witnessed incredible loss of life and limb, and total destruction of property. Every kind of structure imaginable was devastated, including 'earthquake-proof' high rise buildings in the capital. It was puzzling after the quake to see engineers from the U.S. swarming over these buildings, trying to find out how they performed contrary to projections previously made on paper. Everywhere that natural soil structure had been disturbed by human hands there was subsidence and landslide. Road cuts, house pads, landscaping, and even retaining walls in terraced gardens were destroyed. Even in unmanipulated soil, trees with their whole root systems were torn from the ground. The ground shook so violently that we were barely

able to scramble on hands and knees from our collapsing adobe home. Hands, feet, and knees bled from the jolting action of the earth smacking against our skin. The only structures that survived were thatched or metal roofed houses of Indians, who built walls with bamboo or cornstalks. Our personal recommendation is not to build any heavyweight structures near a tectonic fault system capable of major earthquake, such as the San Andreas fault system located along the West Coast of the United States."

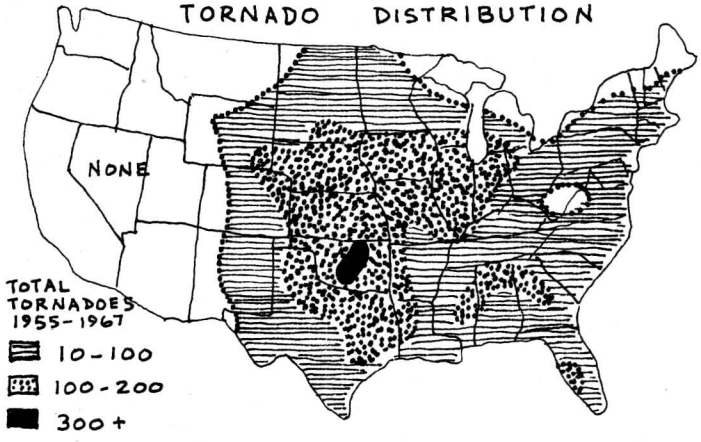


FIGURE 2.2 Taking shelter underground is traditional tornado protection in the Great Plains.

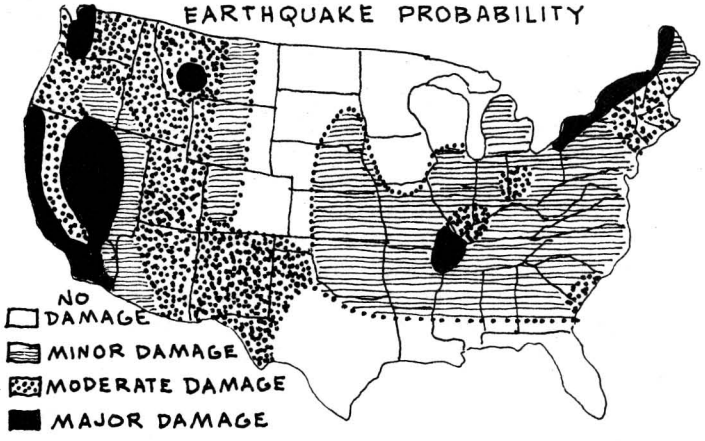


FIGURE 2.3 Underground homes may reduce some destructive forces in moderate earthquakes. However, they are untested under the stress of major earthquake.

Groundwater. Where there is groundwater, there is an insidious force which money and time may not be able to overcome. Below groundwater level, hydrostatic pressure is 62.4 pounds per square foot for each foot of depth (500 pounds per square foot at a depth of eight feet). In this circumstance, you may well question whether your commitment to underground building is a rational one. We recall the myth in which Sisyphus is forever doomed to roll a rock uphill only to have it roll down again. He is required to do it over again, endlessly---like trying to patch a leak in an underground house sited in an area of high groundwater. If you anticipate high levels of groundwater at your site or if it surfaces during excavation, reconsider your building plans. Locating a leak in conventional above grade structures is difficult enough. Water will often move in marvelous and mysterious ways before it reveals its source. In an underground structure, a leak is much more difficult to locate and repair.

It is necessary to understand the properties of soil before you attempt to integrate housing and soil. Whether soil analysis is to be done intuitively as Baldasare did by just taking the time to experiment, or whether by engineers drilling core samples and charging a wheelbarrow full of money is up to the owner-builder. By working with your soil a full year in order to observe the full range of seasonal variations in its behavior, you will understand better what to expect from the material which will surround and cover your house. By knowing something of your soil's percolation, you will recognize some of the ground water problems which may be encoutered, and anticipate requirements for a greywater disposal system. You will perceive how relatively easy the course of building construction may be expected to be, and how replanting and landscaping will be done. An underground structure built of concrete should last for centuries. The planning phase should be unhurried to reflect that intent.

FIGURE 2.4 These soil characteristics, compiled for engineering dams, are applicable to earth sheltered housing.

	Name	Value for Foundations	Dry Weight lb/ft^3
GRAVEL AND GRAVELLY SOIL	Well-graded gravel or gravel-sand mixtures, little or no fines	Good bearing value	125-135
	Poorly-graded gravels or gravel-sand mixtures, little or no fines	Good bearing value	115-125
	Silty gravels, gravel-sand-silt mixtures	Good bearing value	120-135
	Clayey gravels, gravel-sand-clay mixtures	Good bearing value	115-130
SAND AND SANDY SOILS	Well-graded sands or gravelly sands, little or no fines	Good bearing value	110-130
	Poorly-graded sands or gravelly sands, little or no fines	Good to poor bearing value depending on density	100-120
	Silty sands, sand-silt mixtures	Good to poor bearing value depending on density	110-125
	Clayey sands, sand-silt mixtures	Good to poor bearing value	105-125
SILTS AND CLAYS	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Very poor, susceptible to liquefaction	95-120
	Inorganic clays of low to medium plasticity, gravelly, sandy, silty, and lean clays	Good to poor bearing	95-120
	Organic silts and organic silt-clays of low plasticity	Fair to poor bearing, may have excessive settlements	80-100
	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor bearing	70-95
	Inorganic clays of high plasticity, fat clays	Fair to poor bearing	75-105
	Organic clays of medium to high plasticity, organic silts	Very poor bearing	65-100
	Peat and other highly organic soils	Remove from Foundations	

Drainage Characteristics	Compressibility & Expansion	Frost Action	Value for Embankments
Excellent	2	1 to 3	Very stable, pervious shells of dikes and dams
Excellent	2	1 to 3	Reasonably stable, pervious shells of dikes and dams
Fair to poor	3	4 to 5	Reasonably stable, not particularly suited to shells, but may be used for impervious cores
Poor to practically impervious	4	4 to 5	Fairly stable, may be used for impervious core
Excellent	2	1 to 3	Very stable, pervious sections, slope protection required
Excellent	2	1 to 3	Reasonably stable, may be used in dike section with flat slope
Fair to practically impervious	3 to 5	4 to 6	Fairly stable, not particularly suited to shells, but may be used for impervious cores or dikes
Poor to practically impervious	4 to 5	4 to 6	Fairly stable, use for impervious core for flood control
Fair to poor	4 to 5	5 to 7	Poor stability, may be used for embankments with proper control
Practically impervious	5	5 to 6	Stable, impervious cores and blankets
Poor	5 to 6	5 to 6	Not suitable for embankments
Fair to poor	4 to 5	5 to 7	Poor stability, core of hydraulic fill dam, not desirable in rolled fill construction
Practically impervious	6	5	Fair stability with flat slopes, thin cores, blankets and dike
Practically impervious	6	5	Not suitable for embankments
Fair to poor	7	4	not used for construction

Values for Compressibility/Expansion and potential Frost Action

1 none
2 almost none
3 very slight
4 slight
5 medium
6 high
7 very high

Unit dry weight measures compacted soils.

Chapter 3

Construction Modes: Dugout, Cut-and-fill, Covered-over

The owner-builder who contemplates building underground may choose from three modes of construction. Living space may be carved entirely from the earth, as was Baldasare Forestiere's homeplace. A second method, called cut-and-fill, uses earth excavated from a hillside as backfill against walls and as sod for the roof. Both the Kern studio and the Mullan house were built in this manner. A third way is to build on level ground, waterproof, and cover the structure with soil and plants. The Zanetto house typifies this construction approach.

Dugout. Throughout history, the dugout system of underground building has been widely used. In pre-industrial times, builders the world over took advantage of unique soil structure and drainage features in their area to carve out underground homes for themselves. Today, in the loess belt of China, large parts of the provinces of Human and Shanxi have porous silty soil beneath which ten million people have dug homes thirty feet or more below the surface, reserving topsoil for intensive cultivation. In some areas of France, vineyardists of the 19th century hollowed out inexpensive homes beneath valuable cropland. On this continent, however, few Native Americans and fewer immigrants have implemented dugout construction.

Baldasare Forestiere's underground digs is an exception. It is surprising that no one else in the Fresno area has attempted this type of construction in hardpan soil. Many places in the San Jaoquin Valley would benefit by use of Forestiere's model, which provides unique, attractive shelter, a subsurface microclimate for trees and vines, fertile soil above for orchards, fish ponds, and a positive visual impact for

the surrounding community. Instead, in the hot Central Valley, the order of the day is wholesale destruction of fig and citrus orchards and their replacement with a clutter of poorly designed, shoddily built tract homes and shopping centers. An energy-sapping air conditioner tops every roof. It is a bitter irony that we call this kind of development "growth."

While we gain inspiration from the aesthetics, energy efficiency, and conservation of valuable cropland offered by dugout construction, there is limited possible application of this building method in our country. With modern structural and waterproofing materials, however, it is possible to build underground structures using other techniques.

Cut-and-fill. This method of construction is commonly used to build underground homes. A building site is excavated, and a shelter is constructed and waterproofed. Excess earth from the excavation is used to backfill around the building and over the roof. The weight of the earth and hydrostatic pressure will vary depending on the soil type and how deeply the house is buried. The strength of structural members will depend on how much sod is to be placed on the roof and behind walls.

Because soil does not have outstanding insulating properties, it is not beneficial to bury a home deeply for that reason. Earth should be considered a temperature moderator rather than an insulator. Many feet of

FIGURES 3.1-3.4 Cut-and-fill construction sequence.

FIGURE 3.1 Layout marked on site with lime.

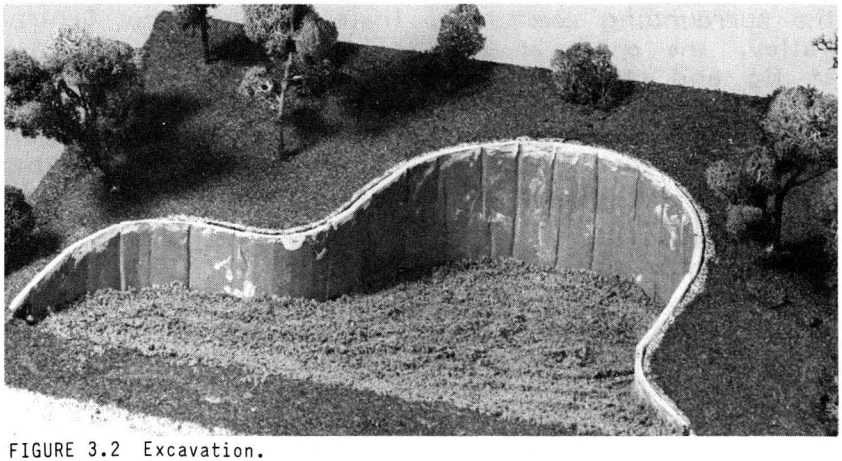


FIGURE 3.2 Excavation.

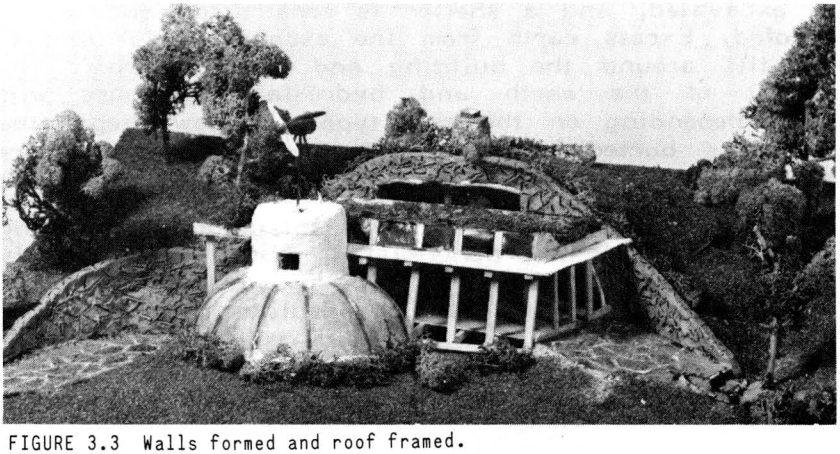


FIGURE 3.3 Walls formed and roof framed.

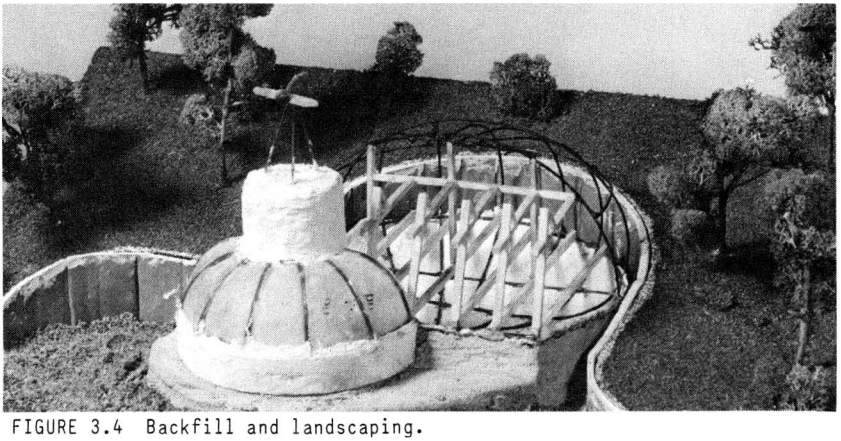


FIGURE 3.4 Backfill and landscaping.

dirt have to be placed on the roof of a building to realize any degree of insulation, and that value is rapidly offset by the cost of the structure to support it. Earth is 5 percent as effective as the best insulation materials.

Thermal Earth Blanket. Great thermal storage capacity is the real advantage of an earth cover. The earth mass surrounding the building gradually absorbs heat, and loses this heat slowly as well. This thermal lag is as effective in summer cooling as in winter heating. The thermal earth blanket covers the living space and protects it from temperature extremes.

Daily temperature fluctuations can be tempered by as little as eight inches of earth cover. Seasonal temperature fluctuations require greater amounts of earth mass if summer warmth is to be carried over into early winter and winter coolth extended to early summer.

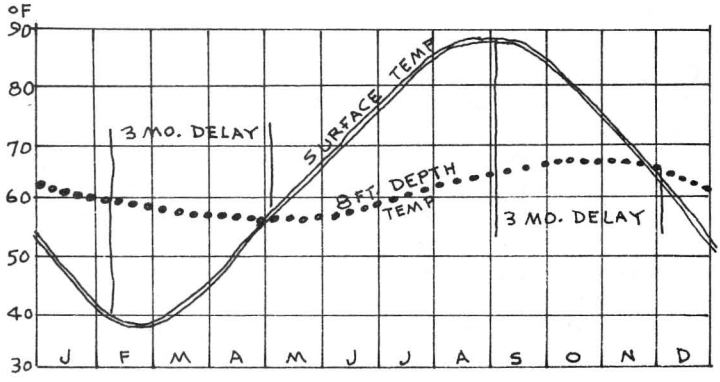


FIGURE 3.5 Surface temperatures of winter cold and summer heat are delayed three months underground.

Stable earth temperatures are reached at a depth of about ten feet, depending on soil type and groundwater level. Generally it is not feasible to make use of this constant temperature except at floor level and at the bottom of walls. Again, structural support costs soon negate apparent advantages when heavy earth fill over the roof is considered.

Air Infiltration. Air infiltration in an earth sheltered home is appreciably less than in an above ground structure. Elaborate barriers to air infiltration are necessary only where the underground home is exposed to weather. Their low profile reduces air

turbulence and the resulting pressure differentials that intensify the penetration of air into buildings.

An earth sheltered home might best be considered a solar home first and an underground home second. The thermal advantages of simply building underground do not equal the winter heating of the sun available to the passive solar home. For this reason, a south facing hillside is the best site. Simple observation of fall and spring frost patterns will reveal that earth temperatures are higher on south facing slopes. With careful design, east or west orientations can be used effectively by burying a south facing home into those hillside exposures.

Cut-and-fill was the technique used to build both the Kern studio and the Mullan residence since both sites were located on south facing hillsides. Each of these projects is examined in detail in ensuing chapters. There are even newer techniques being used to build underground. One of these, the double shell or "envelope" house design, would appear to work well in combination with earth sheltering.

Covered-over. There are significant features to the covered-over approach that make it particularly suitable for use by the owner-builder. The structure is first built on flat ground, waterproofed, and then covered with earth. With other approaches to underground construction, excavation sometimes reveals problems with the building site, such as the presence of an expansive clay soil, impervious layers of rock, or a high water table. In any of these circumstances, it would be advisable to build on ground level, then cover the structure with earth after its completion.

Another feature of covered-over housing is its repairability, an aspect almost totally ignored by writers of the present literature on underground housing. For the owner-builder, consideration of this aspect of building underground is essential; it will be you who both builds and repairs the structure. If leaking occurs in a contractor-built house, today's homeowner is likely to move out and bring suit.

Obviously, with less earth cover there will be less weight and water pressure to cause leaks. If structural failure or leaking does occur, there will be less backfill to remove for repairs. Covered-over underground construction benefits from earth sheltering while using only enough soil to sustain plant growth on the roof and to cover walls. The Zanetto project, examined in detail in the next chapter, illustrates the point

that in certain climates there is little advantage to using more than minimal earth covering.

Because structural loading on these buildings is reduced, the builder has considerable flexibility in the choice of building material and design. In addition to concrete and steel, wood, bamboo, soil cement blocks, stabilized clay, and other site-generated materials may be used. Costs are lower partly due to the ease of construction. The use of sod roofing and an earth berm will soften the visual impact of new homes, whether in urban, suburban, or rural settings.

In 1965, French architect Guy Rottier, an early proponent of covered-over structures, first proposed building "tube" housing. These structures of reinforced concrete are built on the ground and covered with earth. Their form is relatively indestructable, for their egg shape is difficult to crush when pressures against it are equal on all sides. Thus, Rottier's tubular structures may safely be covered with large quantities of earth. In fact, a certain amount of top fill is necessary to insure the lateral stability of these shells. This amount is calculated as 12 percent of the tube's span. Backfill for the tubular house is intentionally compacted to achieve maximum density, which strengthens the tube.

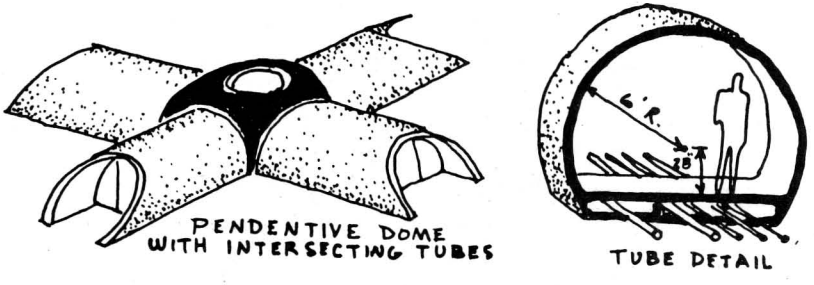
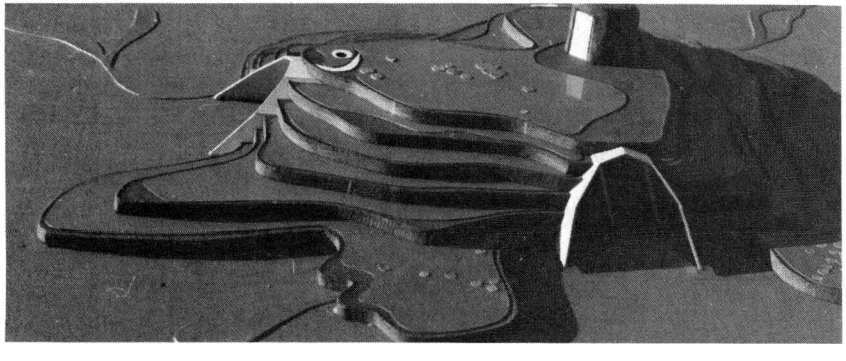


FIGURE 3.6



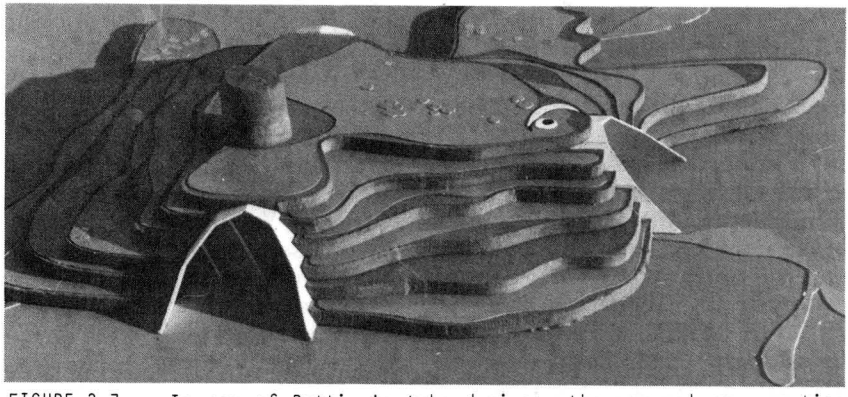
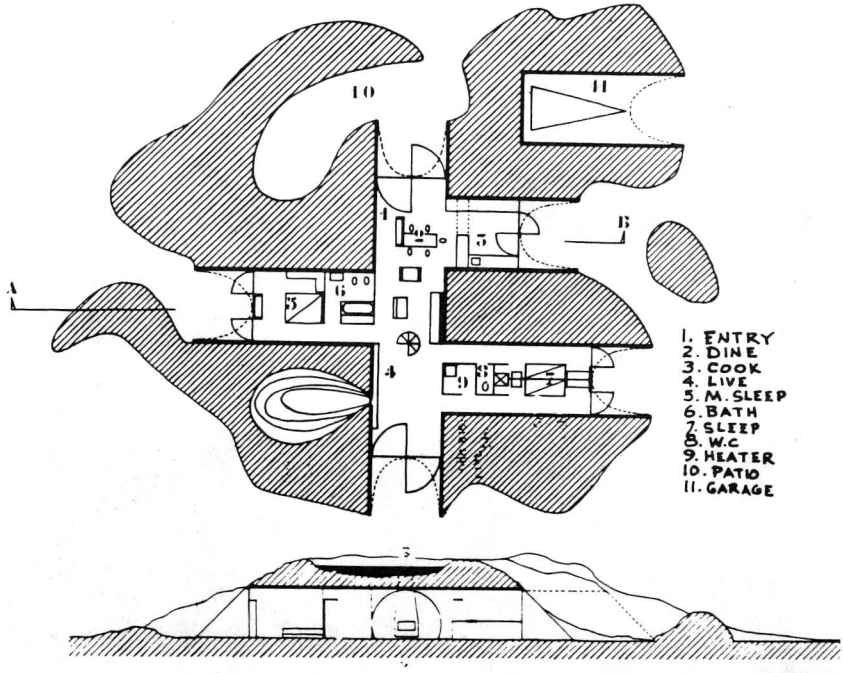


FIGURE 3.7 In one of Rottier's tube designs, the covered over portion was terraced and flooded with water, creating a landscape reminiscent of Indonesian rice fields. A spiral stairwell connects the roof pond to the building interior. Rottier favors the use of roof ponds and extensive garden development around his covered over tube designs. This is one of the most fruitful uses of otherwise wasted roof area.



FLOOR PLAN & CROSS SECTION
FIGURE 3.8

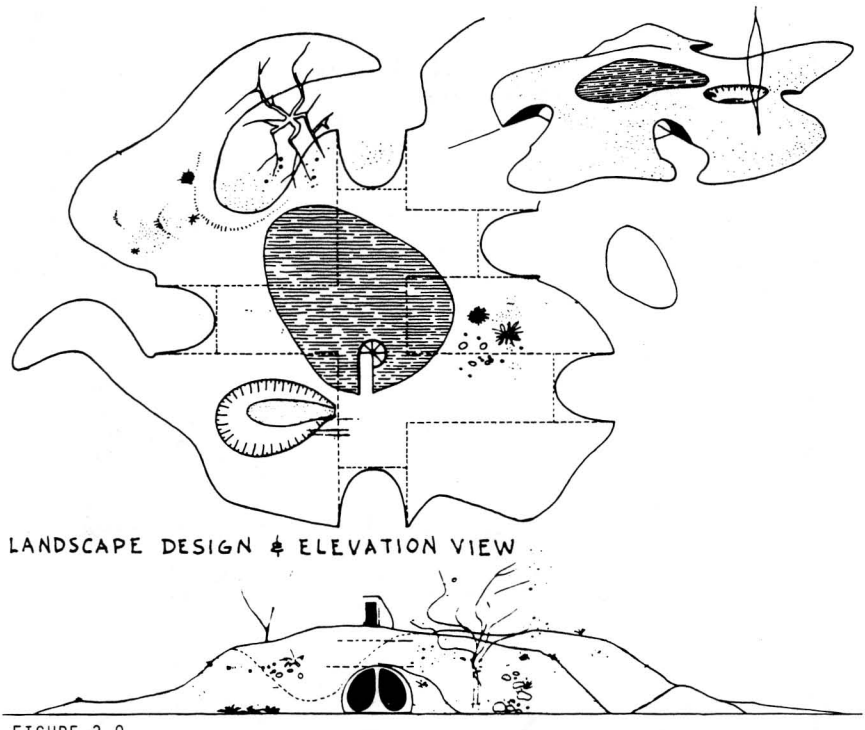


FIGURE 3.9

FIGURE 3.10

Culvert pipes. Covered-over tubular building construction has recently been promoted in this country by designer Hermann J. Von Frauhoffer. His innovative structures use corrugated galvanized steel culvert pipe, such as that employed to erect storm sewers and build drainage conduit beneath roadways. Arched sections of corrugated pipe are bolted together on the site. Many different configurations are possible. Some of the more popular of these are seen in the illustration. Culvert pipe is manufactured by companies like Armco and Republic Steel.

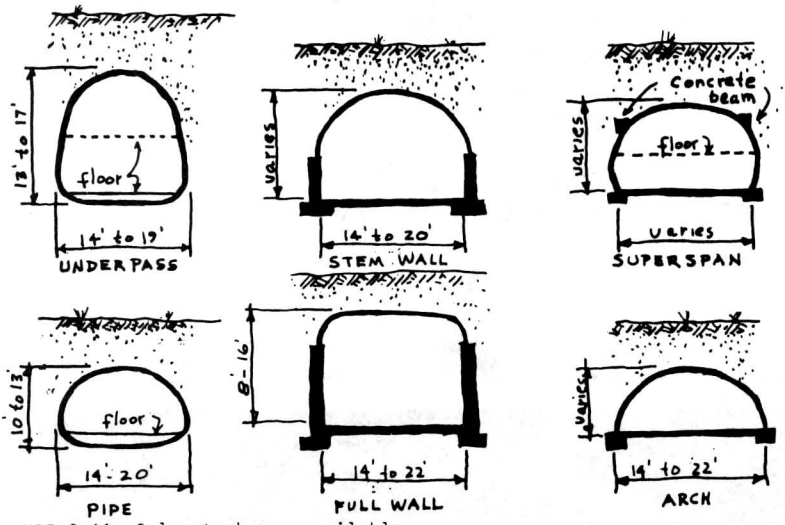


FIGURE 3.11 Culvert shapes available.

The shape entitled "underpass" is practical when building a two-story structure, since it does not require a concrete footing for its support. The "stem wall" and "full wall" designs also lend themselves to multi-level construction. The resulting perpendicular wall space appeals to those who find inwardly curving single story wall areas difficult to furnish. Wide spaces are possible with the "super span" model which uses continuous concrete beams to bridge interior space. This design, as well as the "arch shape," requires minimum footing support that can be cast as an integral part of the floor slab.

However, there are disadvantages for the owner-builder in the use of culvert pipe for underground house construction. When we contacted a West Coast

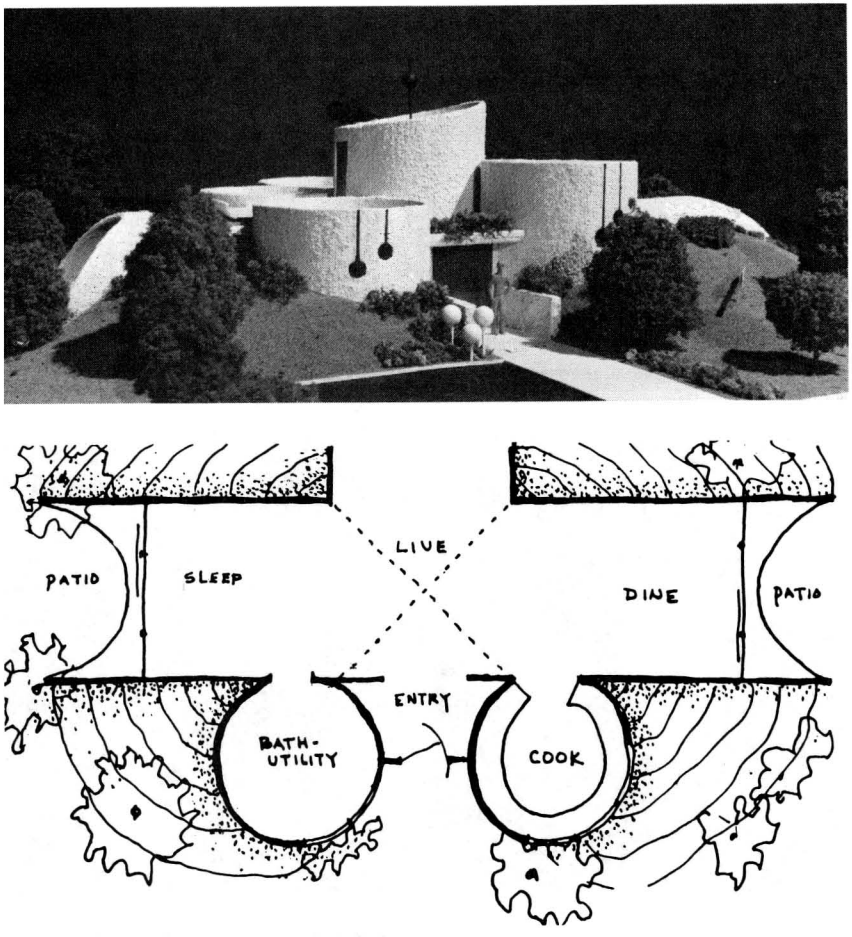


FIGURE 3.12 Von Frauhoffer illustrates a variety of culvert floor plans in his book, The Housing Alternative. Pipes can be placed both vertically and horizontally.

agent for Armco, he reported that current company policy discourages the use of culvert sections for home building. The company would not stand by its engineering statistics for the pipe nor would they sell the product with any guarantee if it was to be used as the shell for a habitable underground structure. Also, prices for the pipe are too costly for most owner-builder budgets.

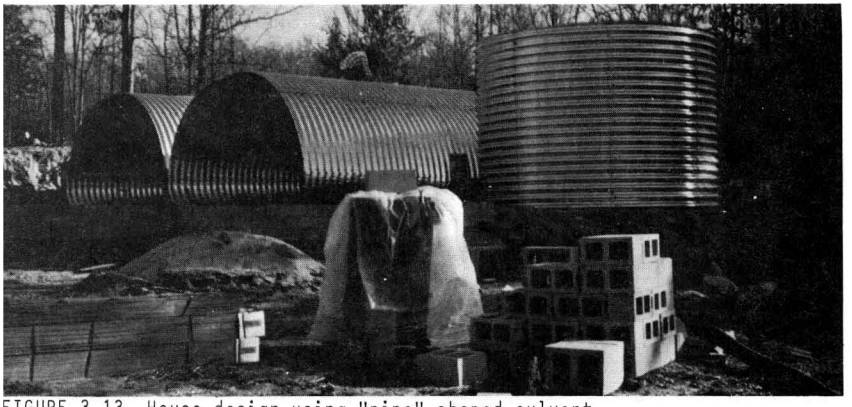


FIGURE 3.13 House design using "pipe" shaped culvert.

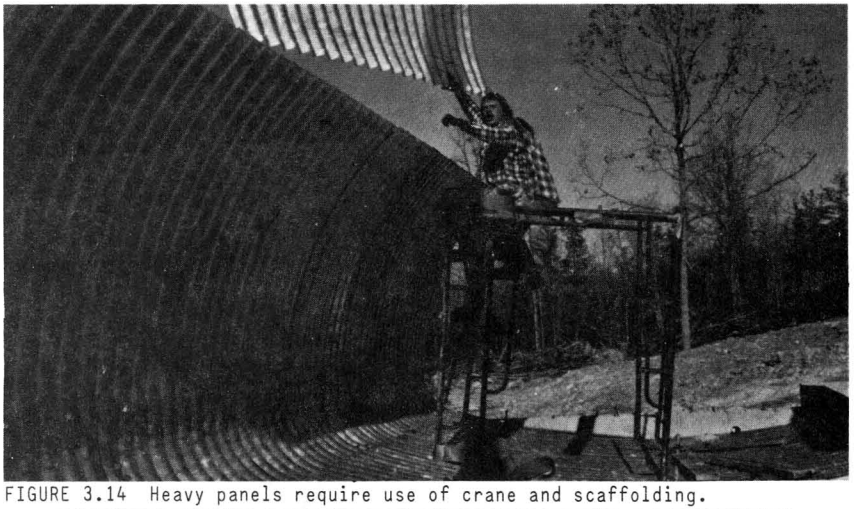


FIGURE 3.14 Heavy panels require use of crane and scaffolding.

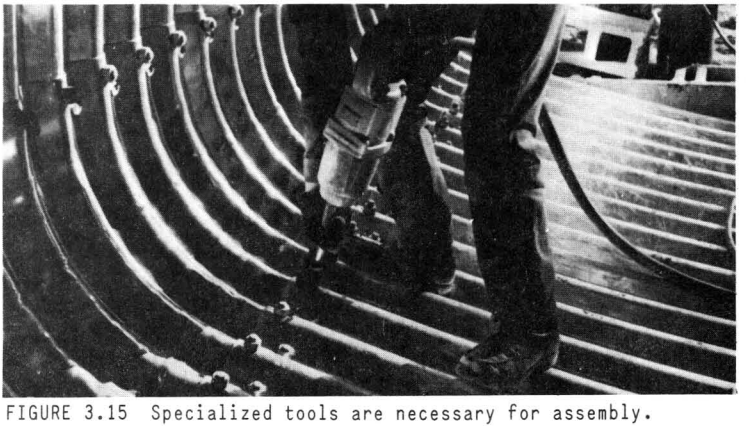


FIGURE 3.15 Specialized tools are necessary for assembly.

Once installed, a shell of cold, ripply steel culvert must be finished with a warm, pleasing interior, using material such as plaster, wood, or sheet rock. This necessitates making a great number of costly and time consuming steel-to-wood (or wire) connections. The inside of many early culvert homes was sprayed with urethane foam. Updated fire codes now disallow application of this highly flammable, toxic material. In addition, urethane loses 25 percent of its insulating capacity in ten year's time. Is this degeneration being dispersed to the residents in the form of toxic outgassing? We feel that the burden of proof for the safety of any and all consumer products should rest entirely with the manufacturer. The consumer has for too long been used as a guinea pig.

Once the culvert form is covered with earth, it can not be checked for deterioration. Steel culverts will rust when in contact with damp earth. In addition, culvert sections are heavy, requiring the owner-builder to hire a large truck for transport and a crane for placement.

Masonry tubes. Many other newer types of tubular contruction do not have these problems. The innovative Bernold system was developed by the Swiss and is manufactured by United States Gypsum, Metal Products Division, 101 S. Wacker Dr., Chicago, IL 60606. This system uses ribbed, perforated steel panels in 4-foot by 4-foot modules that weigh 50 pounds apiece. The panels are quickly connected with steel pins to create a form that is also reinforcement for a coat of concrete. Concrete is usually applied by the sprayed-on "gunite" or "shotcrete" method. (Inquire at local concrete yards to learn whether this service is available to you.) The cost of shotcrete is $.50 per square foot per inch of thickness (1982 estimate). The company will custom bend plates to a desired radius, claiming its system of construction cuts time, materials, and labor costs and results in a superior thin-shelled, load-bearing arch.

Various waterproofing materials could be applied to the smooth exterior concrete surface of the Bernold system. Styrofoam insulation board would be installed over this water barrier. Interior surfaces would function effectively as thermal mass and are of finish quality when the gunite or shotcrete process is well done. Sound dampening may be necessary with this hard surface however.

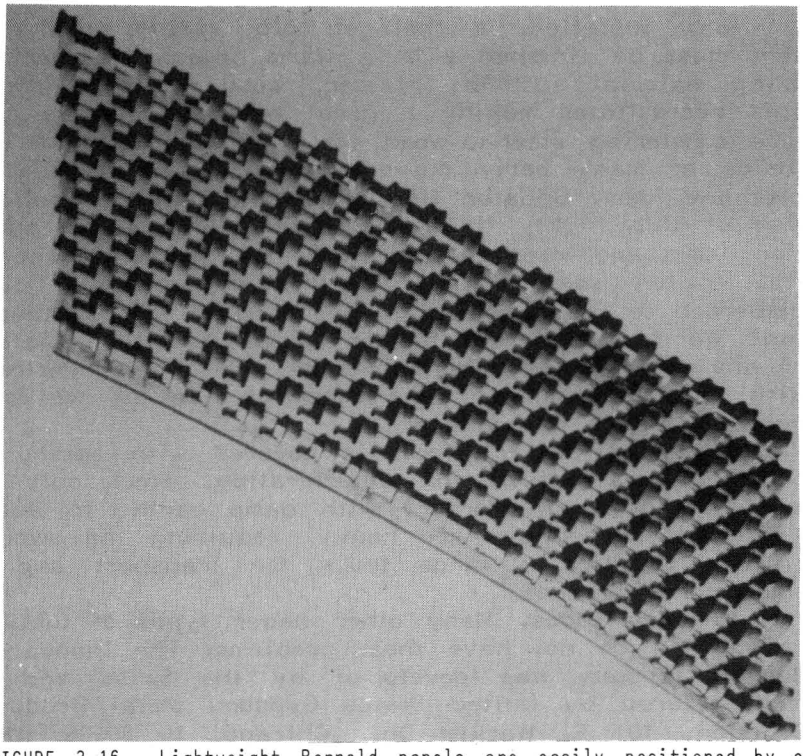


FIGURE 3.16 Lightweight Bernold panels are easily positioned by one person. Panels are custom bent to the specified arc.

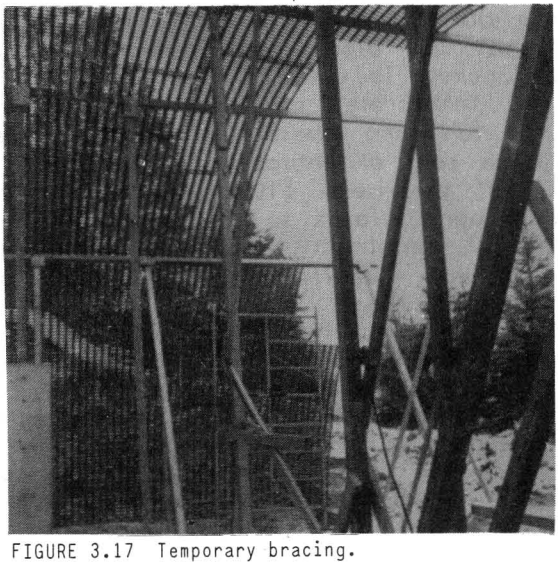


FIGURE 3.17 Temporary bracing.

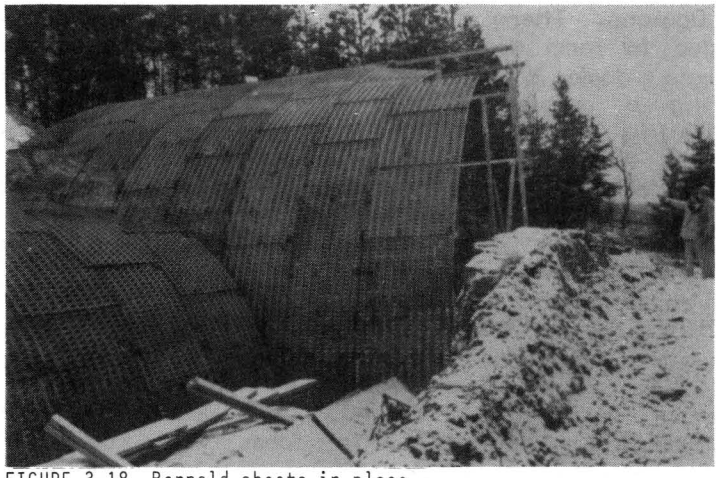


FIGURE 3.18 Bernold sheets in place.

FIGURE 3.19 Formwork covered with concrete; retaining walls poured.

The Bernold system could be erected by owner-builders, since neither skilled labor nor expensive equipment is required. A manufacturer's representative stated that the company would cooperate with owner-builders, who are beginning to order these systems. He also stated that "while an individual owner could easily erect a Bernold arch, it is essential that an architect or structural engineer perform or at least review the design." Their informational packet contains engineering data that would simplify this structural review.

Options. There are numerous ways for the owner-builder to form domes and arches. Paola Soleri built a concrete dome by piling dirt in the desired shape, pouring a reinforced slab over the mound, and then excavating the sand out from the interior. It would be more economical to coat ferrocement over an earthen form. Another alternative would be to apply ferrocement over a form using the shotcrete method. In this technique, one-inch steel fibers are mixed with mortar and water in the nozzle of the shotcrete "gun" and sprayed on by air pressure.

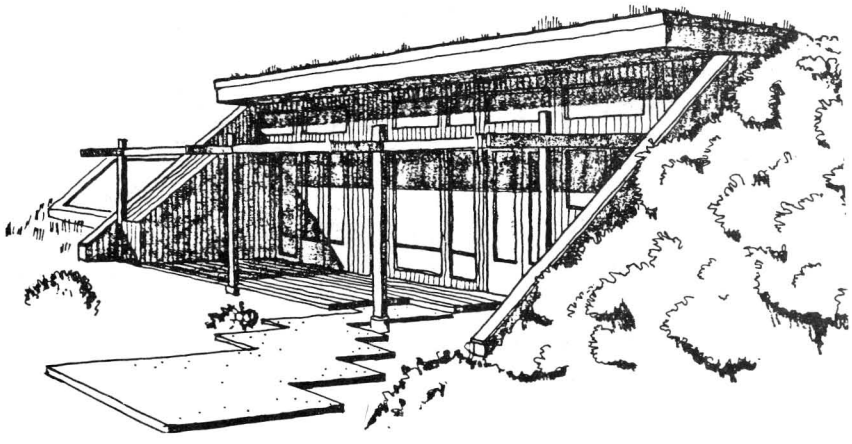
In the 1970's, a demonstration geodesic dome was built in a cooperative community garden in New York City. Triangular-shaped panels for the dome were made of recycled cardboard, bent along their edges and stapled together. This form was covered with several layers of chicken wire, which was given a thin coat of mortar. The inner cardboard form was then removed, leaving a strong thin-shelled dome storage shed for the co-op gardens. There is no limit to the numerous possibilities for building arches, domes, and vaults using low cost structural techniques such as ferrocement.

Thin-walled arches or domes may be quite feasible and attractive when various lightweight backfill materials are used instead of soil. Expanded mica, vermiculite, or perlite may be used beneath a thin covering of soil for support of plant growth. The weight of backfill and hence structural loading on the shell is thereby reduced. Use of leaf mulch, composted rice hulls, or various other kinds of compost may be viable alternatives to the use of heavy soils as backfill. Reduced loads from the use of lightweight materials are a trade-off for the reduced thermal storage capacity of the lighter berms.

Wood and other materials may also be used in construction of the covered-over house. Particularly interesting is use of an all-weather wood foundation. With this design, pressure-treated wood bears directly on a bed of drain rock instead of on heavy concrete footings. This technique is entirely suitable for owner-builder use, and in the next chapter we examine in detail a house built in this manner.

Chapter 4

The Zanetto House



The Zanetto underground home was built in the the summer of 1979 by Jim, Donna, and young Aaron Zanetto, together with Jim's brother Jeff. The house, a simple earth-sheltered residence for a small family, was built on relatively flat ground in an unusual housing development. Called Village Homes, this tract is a visionary project designed by Mike and Judy Corbett of Davis*. It features small lots designed for optimum southern (solar) exposure. Cooperatively owned pathways and commons areas separate adjoining residences. Narrow streets end in cul-de-sacs, reducing non-resident through traffic and street surface area, thereby reducing heat gain during hot California summers. Any landscaping interfering with the solar exposure for another residence is disallowed.

The Zanetto site was one of four lots in an experimental block distinguished from the rest of the development by two features. Earth-sheltered dwellings would be built on all four plots, and there would be no direct street access by automobile to any of these

*A Better Place to Live: New Designs for Tomorrow's Communities published by Rodale Press examines the Village Homes subdivision in detail.

residences. The neighborhood plan is shown in the drawing.

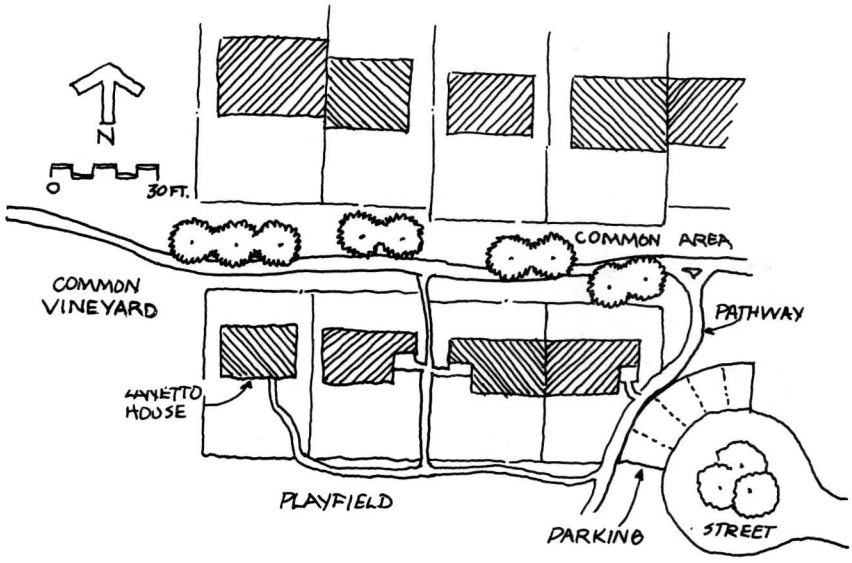


FIGURE 4.1 Lots in the Village Homes subdivision are solar oriented (south facing), and are separated by commonly owned greenways. Automobile parking is provided at the cul-de-sac. Pathways allow foot or bicycle travel to houses. Owners report no inconveniences with this arrangement, since most commute to work on bicycle.

Of these four earth-sheltered houses, the Zanetto residence was the only one built by its owner, while the others were constructed for sale by the Corbetts. The Zanettos received 90 percent bank financing on their house and property. The Corbetts too, received bank financing for their speculative ventures, all of which sold within a short time after their completion. This fact indicates a ready acceptance of earth-covered dwellings by the private business sector as well as the general public. Although these structures were built in a unique housing development, their construction should not be considered an isolated event. Many developments around the country are now being designed after the Village Homes model, and at the time of this writing there are several that feature underground houses exclusively. Before any lot is purchased, the prospective builder of an underground house should carefully examine neighborhood covenents and restric-

tions for this type of building.

To the north of these earth-sheltered houses in the Corbett tract lay a commonly-owned green belt area devoted to gardens as well as fruit and nut trees. The earth-bermed and landscaped Zanetto residence would be viewed as part of this commons greenery by neighbors.

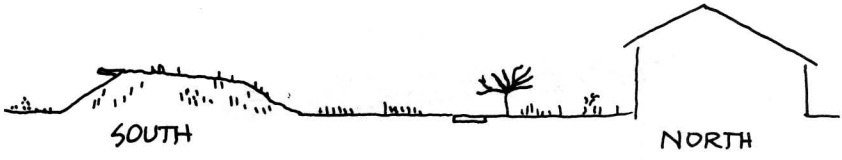


FIGURE 4.2 The low profile of the Zanetto underground residence is appealing. The house blends into the surrounding greenery.

Indoor and outdoor activity areas were oriented to the south to make full use of the sun. On the south side of the structure, an arbor covered with grape vines would protect both house and deck from intense Central Valley summer sun. Full sunlight would bathe them in winter when the vines were leafless. A temporary shade structure is used while the vines are maturing.

Organic Shading. Natural plant shading is in perfect harmony with the seasons. For several weeks after the spring equinox, early foliage is sparse, allowing sunlight to pass between small leaves. This sparseness permits the heat gain needed at this time of year when air and earth temperatures are still cool. In the fall, for several weeks following the equinox, full shade is cast by mature leaves, blocking sunlight and protecting the house from heat gain at a time when the baked earth still holds heat from the long summer. These organic shading techniques are fine-tuned to seasonal variation. If spring is cool and the coming of summer late, the growth of leaves will be slow. If spring is early and of short duration, leaves soon spring forth. With an early fall, leaves turn and drop abruptly or vines may be pruned back just after harvest. During extended periods of summer and fall, grapes readily retain their foliage, basking in the luxury of the long season. With rewards gained from a harvest of fruit and leaf mulch, the good gardener could not create a more perfect shading system. In the summer, retaining walls to the east and west protect the south wall of the Zanetto house

from early morning and late afternoon sun and from winter wind and storms.

On the north side of the house, a small recessed courtyard would permit outside access from the two bedrooms and allow windows to open from the bath. North windows act as a sun scoop, focusing any sunlight striking the large reflective window sill through the small recessed window.

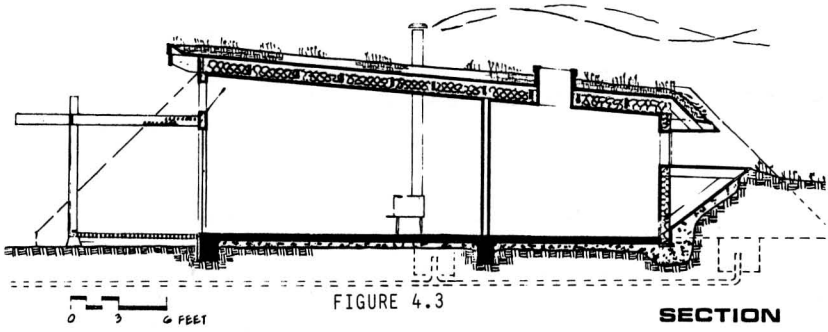


FIGURE 4.3

The house was designed by Jim as a passive solar home, first, and an earth-sheltered home, second. Jim had long desired to build a sod roof but only had opportunity to do so when he built his own home. The original plan called only for extensive berming, but as Jim states, "It was quite a revelation when I first started to draw the earth berming as actually linking up with sod on the roof." From that first drawing of an underground structure, Jim was convinced he and his family would "dig in."

The Zanetto's primary purpose was to design an efficient passive solar home, one that was 100 percent naturally cooled and at least 80 percent solar heated. The house has since performed well and provided much data on the benefits of shallow sod roofs and the use of an earth berm as heat storage mass. House performance is discussed in detail at the end of this section.

Climate. The Davis climate is mild in winter, having only 2800 heating degree days.* There is virtually no snowfall, but persistent ground fog in winter makes solar heating unreliable. The features on which

*The "degree day" is a unit of measurement used to describe heating needs. Degree days are obtained by subtracting the average daily temperature from a 65°F base. For example, 40°(day's high temperature) + 10°(day's low temperature) ÷ 2 = 25° The day in the example is a 40 degree day. Season totals of degree days are used to estimate the size of a solar heating system and backup requirements.

this home relied for its passive solar heating were a large expanse of south-facing glazing and minimum heat loss through walls and roof. Heat gained through glazing during the day was stored in the concrete floor, while insulated, reflective drapes prevented heat loss during hours of darkness. No solar greenhouse or sunspace was attached to this building.

Summers, on the other hand, are quite oppressive, with well over 1000 hours annually in excess of 80 degrees Fahrenheit and requiring 1060 cooling degree days.* Vegetative shading over the south deck prevents most of the sun's rays from penetrating the south window wall, but the reflective drapes need to be drawn to eliminate heat gain by conduction. The mass of the house absorbs the excess heat of the day, while ventilation to the cool night sky dissipates this stored heat. The earth berm on the east, west, and north walls of the building limit heat gain during the day. Heat gain through the sod roof was estimated to be a fifth that of R-30 roofs commonly built in the area. (Village Homes was a good place to compare earth-sheltering with the numerous passive and active solar homes, many of which had been technically monitored to substantiate their performance.) Earth-bermed housing compared favorably with nearby passive solar housing, in which "water walls" were used as the storage medium. Water walls are containers of water that can be anything from translucent fiber glass cylinders to culvert pipes and 55 gallon drums painted black. These are located in the house near south-facing glazing to receive and store solar insolation. However, from findings at the Zanetto residence, it seems that in the Davis climate water walls can be eliminated in favor of an earth berm used in conjunction with passive solar design. In effect, an earth berm creates a separate underground climate so that the building does not undergo thermal stress resulting from extremes of daily temperature fluctuation. This fact will be examined in detail in a latter part of this chapter.

Owner-Builder Methods. Since this home was to be owner-built, Jim used the building methods with which he felt confident and comfortable. Since he and his

*Cooling degree days is a unit measuring cooling needs. The 65^0F base is subtracted from the average daily temperature. A summer day with a high of 110^0F and a low of 50^0F would be a 15 degree day.
$110^0 + 50^0 \div 2 = 80^0$, $80^0 - 65^0 = 15^0$

brother were familiar with the techniques of wood framing, Jim chose to build an all-weather wood foundation.* In that way, no new skill was required as in learning masonry technique. The Zanettos did all of the work on their house except for finishing the slab, running electrical and plumbing lines and applying a waterproof barrier.

The cost to frame a house of this size with wood compared favorably with the cost to build with the masonry techniques more commonly used to erect underground housing. For comparative purposes, the costs to build walls for earth-sheltered structures were compiled several years ago by the Underground Space Center in Minneapolis, Minnesota. Although prices have increased and local conditions and specifications vary greatly, the cost breakdown shows the relative expense of walls using different materials.

depth of earth cover	material				
	wood	conc. block	unreinf. conc.	reinf. conc.	precast conc.
5-6 ft	2.45	2.70	3.75	5.40	---
1 story 2' cover	3.55	3.20	---	5.80	4.00
2 story	7.05	3.60	---	6.45	4.20
2 story 5' cover	---	4.50	---	6.55	4.40

FIGURE 4.4 Approximate wall costs were compiled in the Minneapolis/St. Paul, Minnesota area several years ago by the Underground Space Center. The figures are specific to time and place, and should not be used by owner-builders to calculate actual costs. They show the comparative relationships of some building techniques to their costs.

*An excellent manual entitled All-Weather Wood Foundation System: Design Fabrication Installation is available from the National Forest Products Association, 1619 Massachusetts Avenue, N.W., Washington, D.C. 20036.

Sod on the roof was limited to eight inches in depth. This was sufficient to maintain plant growth but light enough in weight to allow the Zanettos to use a standard 2-by wood framed roof system. A dirt cover this shallow is also the custom in cold Scandanavian countries, where snow cover is the chief insulating factor.

An all-weather wood foundation was used for this structure. No concrete and steel footings were used in this system. Instead, a footing 8 inches deep by 24 inches wide was filled with gravel and leveled. A pressure-treated 2 x 12 "footer" plate was placed on top of the gravel. Then, a wooden stud wall was built and tilted up atop the footer plate. Because this stud wall was to be the retaining wall for the house, it was built of pressure-treated 2 x 8's, 12 inches on center. Sheets of pressure-treated half-inch plywood were used to sheathe this wall on the outside. These were caulked with butyl at each splice. The nailing pattern was close, 6 inches at splices and 12 inches in the field. All nails were required to be stainless steel. It should be noted that the all-weather wood foundation requires a more intensive pressure treatment process than is used in the "foundation green board" commonly available from building materials outlets.

Wood Foundation Construction Sequence. An all-weather wood foundation is a system in which pressure-treated wood bears directly on a rock foundation. The layout and excavation for a building using this system does not differ greatly from that employed in conventional construction.

Batter boards are used to define the area for excavation. To secure strings to batter boards, saw kerfs are cut into the top of the boards. The building is squared with a carpenter's triangle, in this case a 9-12-15 triangle. With one corner squared in this manner, others are established simply by measuring the length and width of the building. To insure that the completed layout is perfectly square, the rectangle is measured across diagonally and adjusted until both diagonal measurements are equal.

The excavation of the trenches is then begun. Underfloor pipes, sumps, drain tiles, and footings are dug. At this point, the similarity to conventional construction ends.

Once tiles and pipe are laid in place, grade stakes made of 2 x 2 pressure-treated wood are pounded in place to aid the leveling of gravel. Two gauge

stakes are driven at the center of the building's layout. Eventually gravel would be filled level with the top of these stakes. Using a carpenter's level to assure their equal height, a series of stakes are driven into the center of the footing excavation. With grade level established, gravel is trucked in and spread even with the top of the grade stakes. Hand work is required to rake the gravel level.

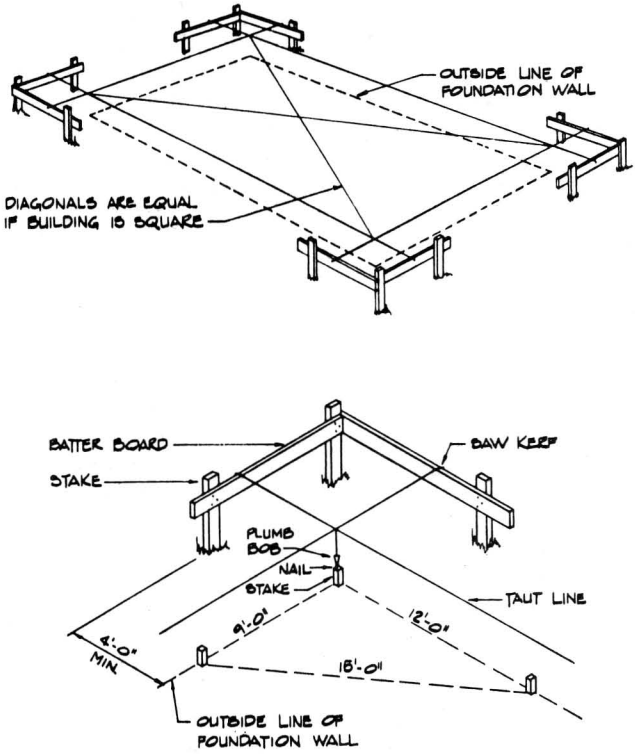


FIGURE 4.5 Layout for the all-weather wood foundation does not differ from standard construction practice. A carpenter's triangle and diagonal measurements are used to square the foundation, marked on batter boards.

Fine leveling of the gravel footing is done before wooden wall footers can be laid down. When the gravel has been leveled exactly, the footer may be laid in place just once, and need not be adjusted to high and low spots in unraked gravel. A homemade footing hoe can be used to do this. To build one, make a straight edge of 2 x 4 material and lay it across the top of two grade stakes. Pre-drill it so

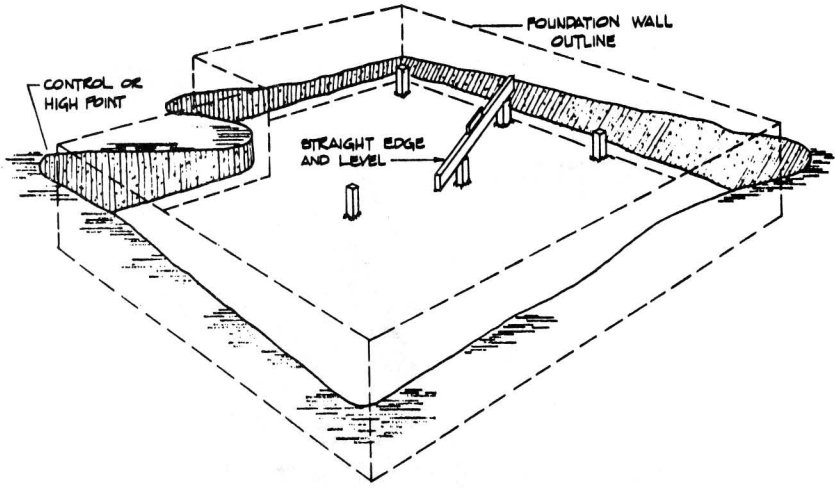
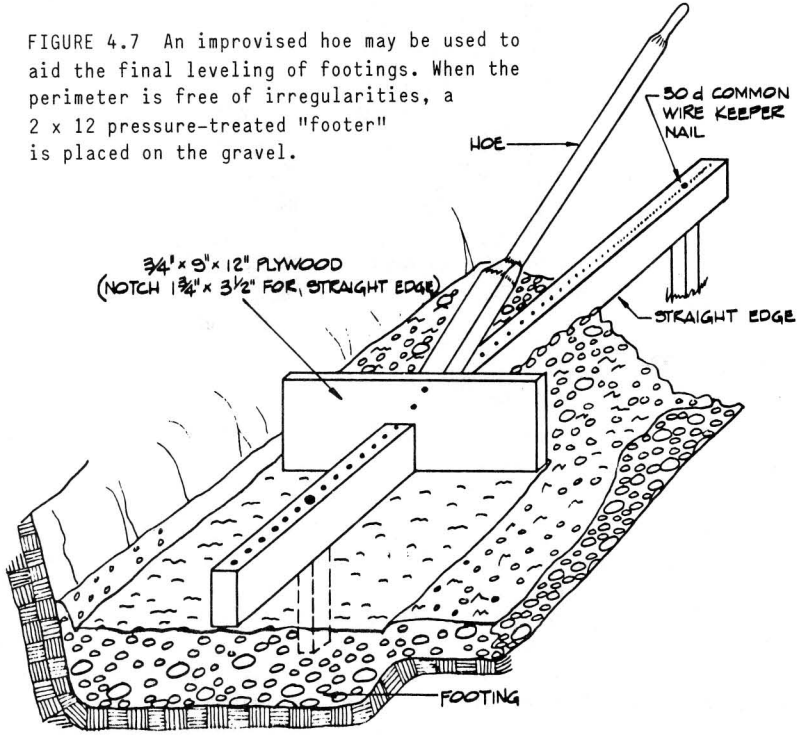


FIGURE 4.6 Pressure-treated 2 x 2 wooden stakes are driven into place to aid in leveling the gravel. Gravel is spread even with the top of the stakes. Because stakes are pressure-treated, there is no reason to remove them after the pad is level.

FIGURE 4.7 An improvised hoe may be used to aid the final leveling of footings. When the perimeter is free of irregularities, a 2 x 12 pressure-treated "footer" is placed on the gravel.



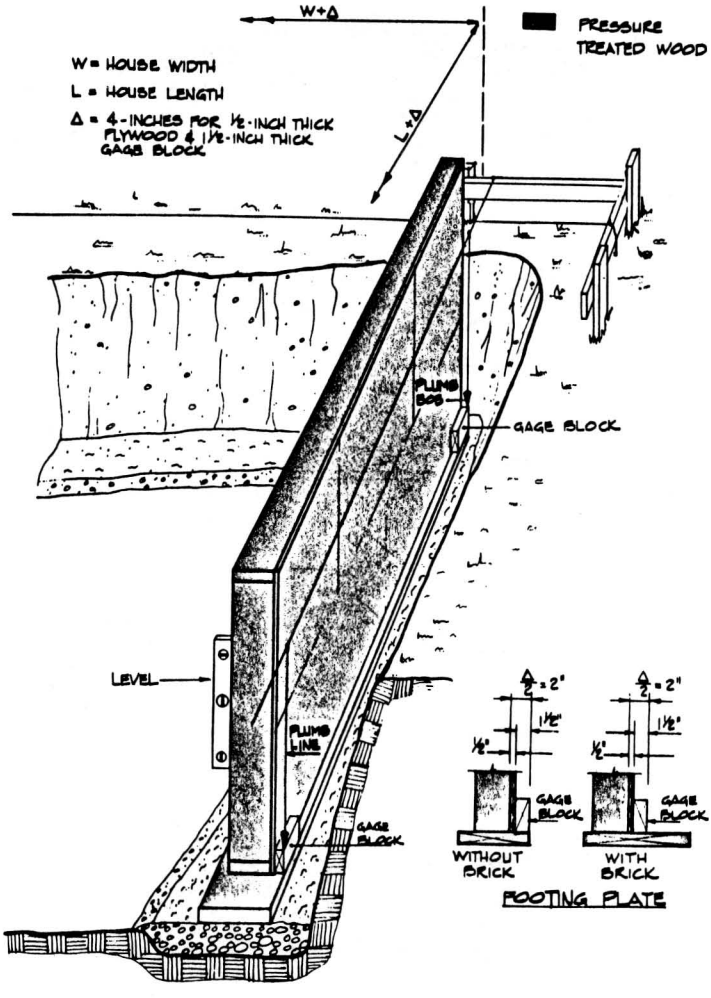


FIGURE 4.8 Wall panels are sheathed with 1/2-inch pressure-treated plywood. Walls are best plumbed with a plumb line.

that 30d keeper nails or gutter nails secure it to the top of the stakes. The hoe has a plywood scraper, notched to ride on top of this 2 x 4 and level the gravel flush with the bottom, as illustrated in the drawing. As this hoe is pulled over the 2 x 4, high spots in the gravel are knocked down and low spots are filled in. There is no need to level gravel in the middle of the building, since subsequent foot traffic

will disturb it. The 2 x 2 leveling stakes are pressure-treated, so they do not have to be removed.

Once gravel footings are leveled, 2 x 12 pressure-treated footers are laid down and walls are built on top of them, similar to standard stud wall framing, although these studs are 2 x 8's, 12 inches on center (stud sizes and spacing will vary according to specific conditions of application). The bottom plate is laid horizontally, along a length of twine. Diagonal measurements are then made across the framed wall to assure that it is square. The wall is then sheathed with 1/2-inch pressure-treated plywood, nailed to a close grid of 6 inches along its edges and 12 inches in the field. It is caulked at the splices with butyl rubber. Making sure there is no gravel between the bottom plate and the footer, the heavy walls are raised. They are plumbed as shown in the drawing.

Above the level of berming, none of the building materials need be pressure-treated, and all of the details are typical of standard framing practice.

The gravel pad between house walls is then leveled, and a floor slab is poured, using the framing as formwork. This saves the time and expense of building forms for a concrete slab.

Above the top plate, none of the building materials need be pressure-treated, and all of the details are typical of standard framing practice.

The gravel pad between house walls is then leveled, and a floor slab is poured, using the framing as formwork. This saves the time and expense of building concrete forms for a slab.

Zanetto Construction Details. The Zanetto construction sequence differed from this typical sequence in that they poured the slab before they built the walls. This change of order required that they build forms, but the south wall as well as one interior bearing wall were made with footings typical of conventional construction, so they would have had to build some form work in any case. The concrete slab then provided a flat surface on which the walls could easily be framed.

The bearing wall in the middle of the house served as a shear wall, with 1 x 6 let-in braces at each end. This wall strengthened the east and west walls, helping them resist any inward-bearing pressure from the earth berm. Roof joists over the living area spanned eighteen feet. Because of their heavy load of sod, these joists had to be 2 x 14's, 12 inches on

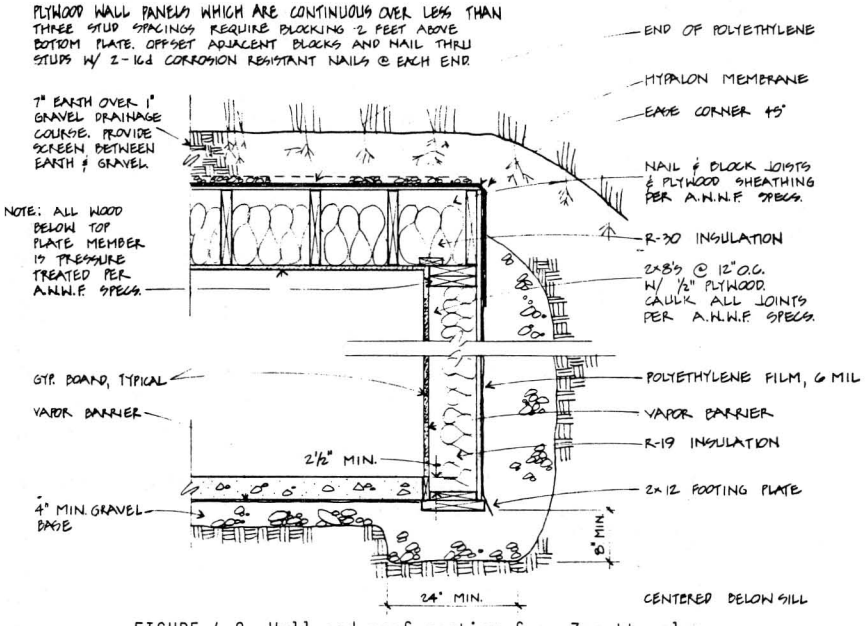

PLYWOOD WALL PANELS WHICH ARE CONTINUOUS OVER LESS THAN THREE STUD SPACINGS REQUIRE BLOCKING 2 FEET ABOVE BOTTOM PLATE. OFFSET ADJACENT BLOCKS AND NAIL THRU STUDS W/ 2-16d CORROSION RESISTANT NAILS @ EACH END.
7" EARTH OVER 1" GRAVEL DRAINAGE COURSE. PROVIDE SCREEN BETWEEN EARTH & GRAVEL.
NOTE: ALL WOOD BELOW TOP PLATE MEMBER IS PRESSURE TREATED PER A.N.W.F. SPECS.
GYP. BOARD, TYPICAL
VAPOR BARRIER
2½" MIN.
4" MIN. GRAVEL BASE
24" MIN.
8" MIN.
END OF POLYETHYLENE
HYPALON MEMBRANE
EAVE CORNER 45°
NAIL & BLOCK JOISTS & PLYWOOD SHEATHING PER A.N.W.F. SPECS.
R-30 INSULATION
2x8's @ 12" O.C. W/ ½" PLYWOOD. CAULK ALL JOINTS PER A.N.W.F. SPECS.
POLYETHYLENE FILM, 6 MIL
VAPOR BARRIER
R-19 INSULATION
2x12 FOOTING PLATE
CENTERED BELOW SILL

FIGURE 4.9 Wall and roof section from Zanetto plans.

center. On the north, over the two bedrooms, joists were 2 x 14's, 24 inches on center. Sheathing for the roof was 1/2-inch exterior grade plywood, nailed to joists that were 12 inches on center. Over joists spaced 24 inches apart, 3/4-inch exterior grade plywood sheathing was used. The blocking between the 2 x 14 joists was 2 x 10's placed flush with the top, but notched to allow air circulation. Blocking was spaced every four feet on center.

Retaining Walls. Retaining walls projecting beyond the interior space on the north and south sides of the house were constructed of pressure-treated wood, combined with a conventional footing of steel and concrete. Footings on the south of the building were tied into the south wall footing with 1/2-inch steel. Numerous bolts connected the bottom plate of the pressure-treated wood wall to the wooden footer boards. Sloping top plates, which formed the hypotenuse of the triangular retaining wall, served as the primary "beam" for this wall. These two top plates were then bolted directly into the footing on the bottom side, and at the top, they were connected to the framing system of the house with sheet metal framing ties. Two-by-eight wall

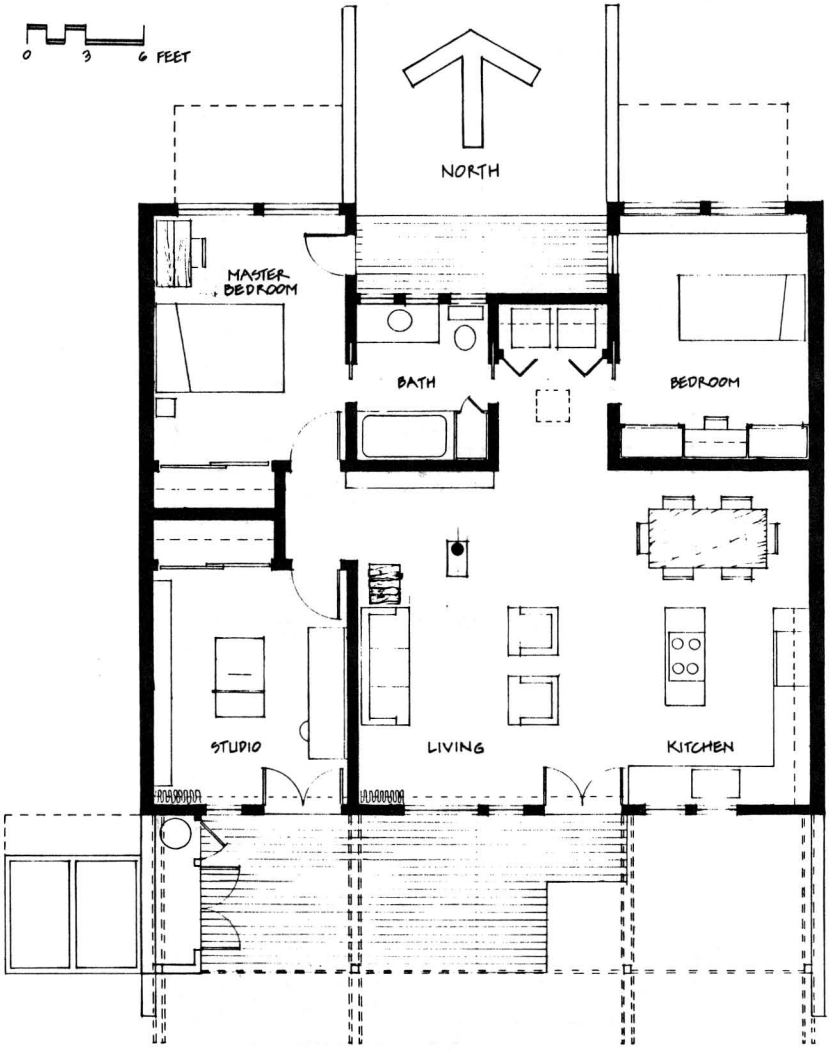
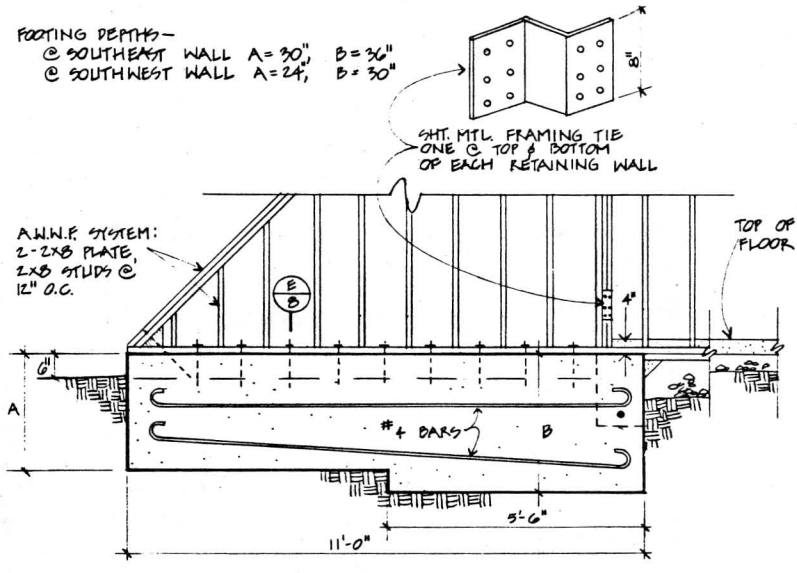


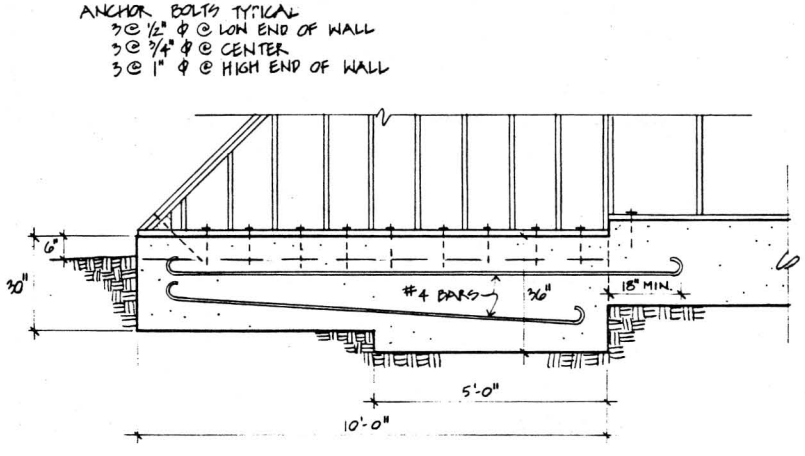
FIGURE 4.10 The Zanetto home demonstrates an efficient and comfortable floor plan for a small house.

studs were placed 12 inches on center and served to span the distance between the top "beam" and the footing.

These walls provided the strength to retain the full height and weight of the earth berm on the outside of the building, and formed the contour to



RETAINING WALL FOOTING @ SOUTH SIDE OF HOUSE
½" = 1'-0"



RETAINING WALL FOOTING @ NORTH SIDE OF HOUSE
½" = 1'-0"

FIGURE 4.11 North and south retaining walls from Zanetto plans.

which the berm would slope as it tapered into surrounding soil levels. These retaining walls did not require a thermal barrier at their joint with the interior walls, as massive masonry walls would have: constructed of wood, they would not conduct heat from inside the house to the outside. These walls were engineered to the precise loads of the Zanetto house and soil in the Davis area.

The Zanettos report that the framing of their house proceeded with few difficulties. The pressure-treated wood with which they worked seemed to be warped and bowed more than standard lumber. This did not create problems with the exterior finish, for the 1/2-inch pressure-treated plywood readily followed irregularities in the plane of the wall. A close nailing pattern held plywood sheathing firmly against any bumps and depressions, and there was no visual impact since exterior work was buried beneath the berm. But on the interior, much planing was necessary to flatten irregular studs in order to achieve a smooth finish for sheet rocked walls.

The strong odor of ammonia, which accompanied the shipment of lumber when it first arrived from the pressure-treatment plant, dissipated rapidly. A carbide blade was required to cut the wood, for pressure-treatment preservatives in the wood quickly dulled regular saw blades. Dust masks were worn during the entire all-weather wood foundation building process, for dust from the cut lumber was toxic and should not be inhaled. Gloves were worn to prevent skin contact. Each cut end of lumber had to be re-treated with a solution of copper arsenate as the project proceeded.

Waterproofing. When framing was completed, the Zanettos turned their attention to the critical area of waterproofing. Like the Mullans, they preferred to use an extensive system of drainage as their first line of defense. Next in line was a moisture barrier. After much study, the Zanettos chose a monolithic rubber membrane called Hypalon. Hypalon is manufactured in San Jose, California by the Burke Rubber Company. This skin is made of 30 mil synthetic rubber reinforced with either a nylon or polyester mesh. It is said to be quite stable and for over thirty years it has been used successfully as a liner for potable water ponds. The material is inert and does not degrade in ultraviolet light, a real bonus since parts of the Zanetto building are exposed to daylight around windows, vent pipes, skylights, chimneys, and near the retaining

wall. This material is not self-sealing when punctured, but it does have remarkable properties of elongation making puncture unlikely under normal curcumstances.

Hypalon is manufactured in continuous rolls that are four feet wide. For the Zanetto house, detailed drawings were submitted to the factory of origin, and six panels were constructed there from these widths. A factory-supplied field crew of two helped the Zanetto brothers install the membrane, laying six panels snugly over the plywood structure. A warm air gun was used to speed drying of the adhesive when the seams were sealed. Trichloroethylene was used to clean the edges of these panels, and a bonding agent was used to glue the cleaned edges together. Proper precautions were taken to assure that neither the cleaning agent nor the bonding agent got on skin or in eyes. Face masks, designed for work with organic chemicals, prevented workers' breathing toxic vapors.

With help from the factory crew, installation of the butyl panel required two days time to seat the six large panels and seal major seams. The Zanetto brothers worked another two days to seal minor seams and complete the detail where the Hypalon meets the facia.

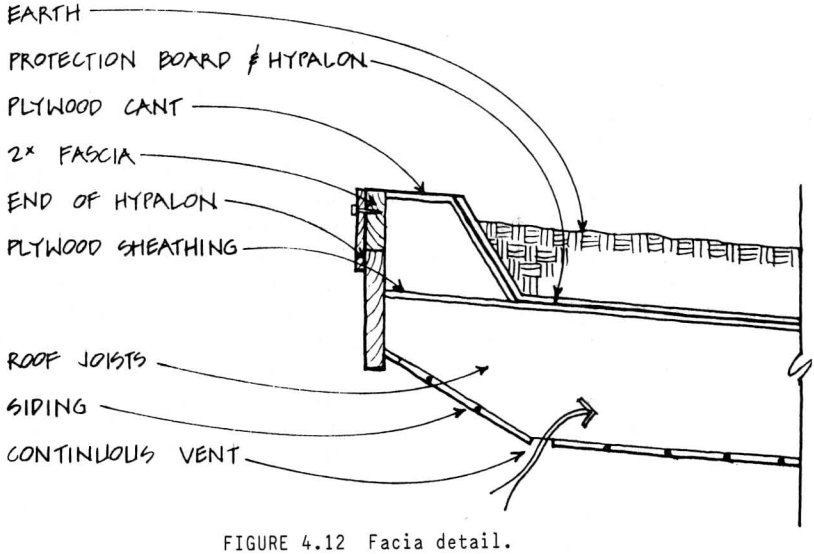


FIGURE 4.12 Facia detail.

Drainage. A gravel drainage system was then installed at the base of house walls. Twelve inches of gravel was placed against the east and west walls. Cloth mesh, used along embankments in highway construction, would separate the gravel from dirt backfill. This drain rock ran up the full height of the wall. Any rainwater reaching this gravel would fall to the building's footings, where it would drain to sumps located in the middle or to the north side of the house.

With two years of service, the Hypalon waterproofing membrane has suffered but one leak, which was caused by puncture with a round point shovel while tilling the roof sod. Locating the leak was difficult, but the rubber membrane was easily repaired by a process not unlike that of patching a bicycle inner tube. The only other cause for concern was that, because the membrane was impervious to degradation by sunlight, it was exposed in many places, making it vulnerable to vandalism or accidental damage. In retrospect, Zanetto recommends covering the Hypalon with either a thin layer of appropriate insulation or other type of protection board able to withstand earth contact. This protection would minimize punctures. The board would be cut into small sections so that minimal digging would be required if repair of the membrane is required.

Breadbox Water Heater. An earth-sheltered solar domestic water heater of "breadbox" design was also built and located on the southwest side of the house. In the mild California climate, breadbox water heaters are becoming commonplace rooftop installations in the Great Valley of California. The breadbox, an insulated box glazed on its south side, contains a series of tanks, painted black. A single tank will work, but the turbulence of incoming cold water will cause variations in temperature of water being drawn by a user. To attain consistent water temperature, a series of tanks is a reliable solution. The glazing usually has movable insulation to prevent nighttime temperature losses.

The Zanetto breadbox was probably the most elaborate, effective, and costly breadbox possible. Surrounded on three sides by earth, only its glazing was exposed. This was done to demonstrate the benefits of earth-sheltering. It also solved the problem of the aesthetics of such a structure. The Zanetto house fits sleekly and harmoniously into its environment. By comparison, an above ground installation would have been

clumsy in appearance. But one wonders if the cost in terms of its possible life cycle will justify investment in this type of installation. Perhaps it best illustrates the marvelous enthusiasm demonstrated by underground home builders.

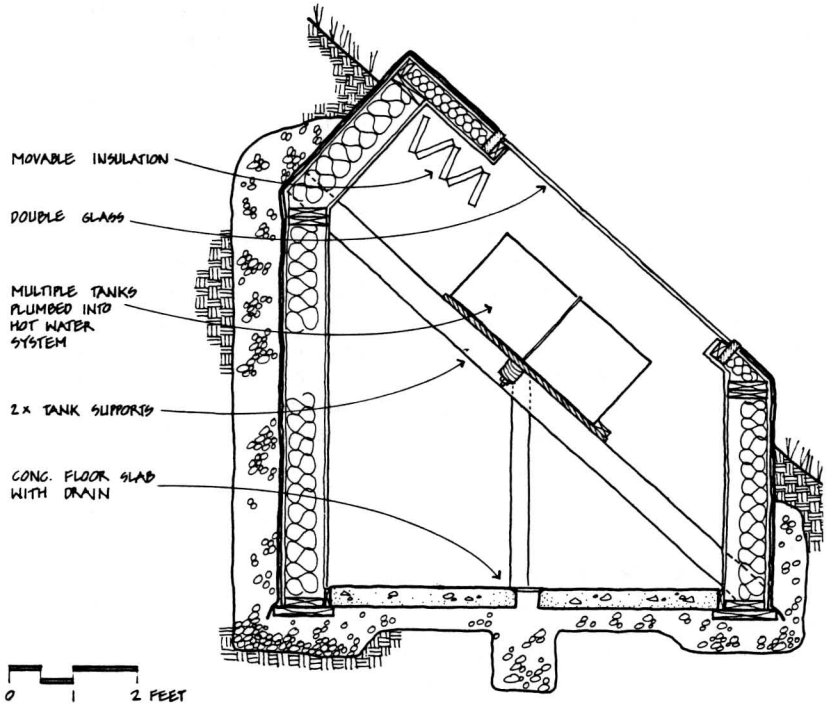


FIGURE 4.13 EARTH SHELTERED BREADBOX SOLAR DOMESTIC WATER HEATER

Landscaping. The most enjoyable work done on this house was its landscaping. Jim and Donna planted 85 percent of the small lot with plants, shrubs, and trees. "We got to put in twice as much landscaping as the typical house in this development," Jim remarks. "It's fairly dense single-family housing here and this was an attempt to relieve that. The view is not so much of another house but of a planted landscape."

Plants were selected either for their low maintenance requirements, as drought tolerance, erosion control for the steep earth berms, or for their ability to take foot traffic. Additionally, rooftop plants had to be able to adapt to the shallow soil conditions.

Rooftop plants selected were primarily ornamentals, some of which were beach aster (Erigeron glaucus), fleabane (E. Karvinskiana), perennial pincushion flower (Scabiosa caucasica), Myoperum plumgren, dwarf coyote brush (Baccharis pilularis), Vinidio Arctotas, California fuchsia (Zauschneria septentrionalis and Z. cana), Verbena tenusecta, and strawberry.

On the berms, different types of manzanita, ceanothus and wild buckwheat (Erigonum) have proven successful. Most of the south yard is devoted to a year-round garden.

Performance Evaluation. The performance of the Zanetto house reveals some important benefits to be derived from using earth-sheltering in the Davis climate. Thirty thermocouples were placed at various locations in the house during construction. The information gathered by sensors was collected in a sophisticated datalogger. Evaluations of the Zanetto house were presented in May 1981 to the American Section of the International Solar Energy Society.

The functioning of this house compared favorably to many passive solar homes in the Davis area, which had incorporated significant amounts of water as thermal mass. Any differences had more to do with the location and function of thermal mass in the various houses studied, since the amount of insulation (walls R-19, roofs R-30) was virtually identical in each. The amount of south-facing glazing was similar in all cases. However, the water wall mass in the living area of the passive solar homes was heated directly by sun shining on it through the south glazing on a winter's day. In summer, this mass is cooled by re-radiating to lower nighttime temperatures. In contrast, mass in the Zanetto home is found in the large quantity of earth placed around the outside of the structure and over its living area. The only significant thermal mass inside the building is the slab floor. Actually, Jim had tentatively planned to include water wall storage in this house but tubes were found unnecessary when the house functioned well without them. Thermal mass blankets this building in benign temperatures issuing from the earth berm. The berm, in effect, creates a separate underground climate around the house, resulting in reduced "thermal stress." Because the house is not exposed to extremes in air temperatures, significantly less mass is required in the structure of the house itself in order to

stabilize its interior temperature within the human comfort zone.

Test Periods. An examination of indoor and outdoor temperatures shows that the Zanetto house performs well in all seasons. Two ten-day periods have been intensely recorded thus far. A February period had cool nights and unseasonably warm days for the first half, and cool, foggy weather for the last half. An October session had hot days and cool nights for the first five days, and cool, rainy weather for the last five.

During these two ten-day periods, the only auxiliary heating or cooling required was on February 7th, at which time two pounds of wood were burned in a woodstove, and on February 8th, when eight pounds were burned. With all of these varying conditions, the house stayed easily within the comfort zone.

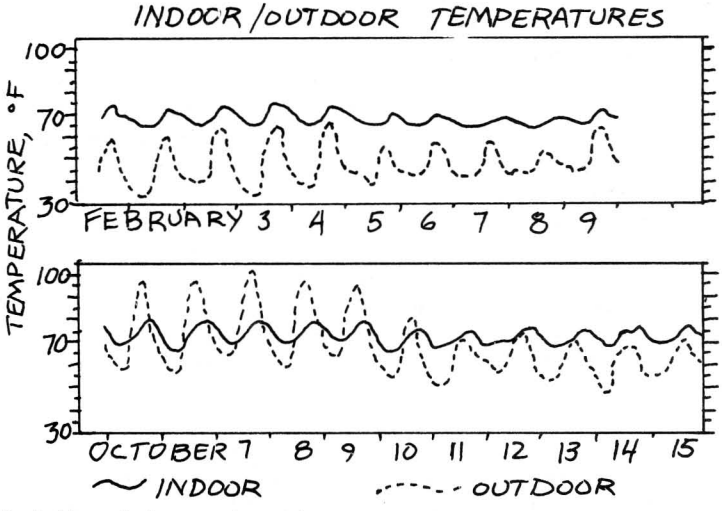


FIGURE 4.14 Indoor and outdoor temperatures were recorded over two ten-day periods. Indoor temperatures were comfortably stable, requiring minimum use of wood heat backup.

For the same two periods, temperatures for the earth berm and the sod roof were recorded. The charts show that even a shallow earth berm has a stabilizing effect, moderating extremes of air temperature. In October, air temperatures ranged over 40 degrees Fahrenheit daily, while soil temperatures at the one-foot level varied only 0.8 degrees Fahrenheit. On October

7th, when air temperatures approached 100 degrees F., temperatures of the shallow sod roof did not exceed 75 degrees Fahrenheit. Berming, at a 10-foot depth, did not fall below 64 degrees F. in February. These findings illustrate the benign blanketing effect of the earth berm.

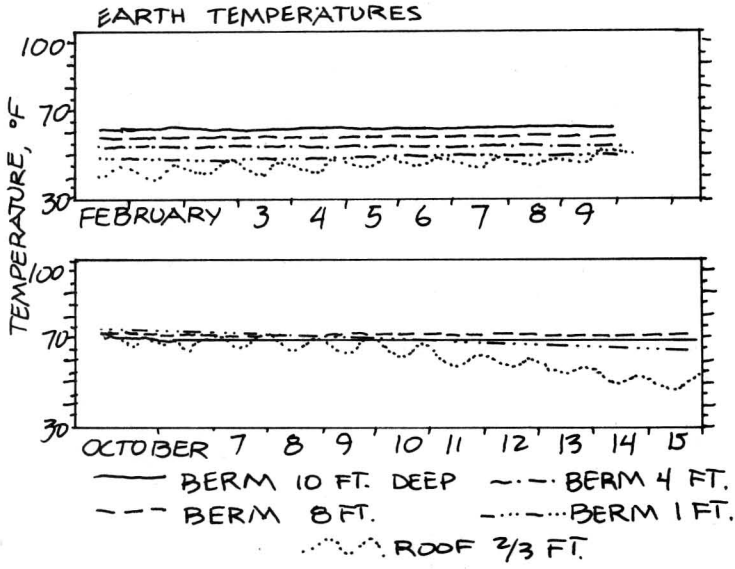


FIGURE 4.15 Temperatures at various depths were collected by placing thirty thermocouples in the berm during construction. Stable earth temperatures are reached at ten feet, but even the shallow earth cover is shown to have a very positive stabilizing effect.

The sod roof seems most appropriate for hot, arid climates. When daily temperatures fluctuated 40 degrees or more, sod at a depth of 8 inches fluctuated no more than 8 degrees F., and stabilized favorably in the low 70s, eliminating any heat gain through the roof of the building. During Davis winter conditions of persistent ground fog and rain, the sod stabilized in the low 40s and proved of little benefit. During periods of clear winter weather, when temperatures swung 30 to 40 degrees, the sod moderated these extremes, tending to stabilize 3 to 4 degrees below the average daily temperature. The shallow sod seems most valuable where there is a significant daily temperature range.

There seems to be little value in increasing the depth of roof cover. The Zanettos have achieved 100 percent natural cooling and a large percentage solar heating for their home. By increasing the roof load with additional sod, they would be unable to use low cost wood framing and would only marginally increase the structure's performance. Heavy sod cover would also increase the difficulty of making repairs on the roof, a problem the Zanettos have encountered already.

Environmental Considerations. From an environmental standpoint, this type of all-wood foundation appears superior to heavy masonry wall construction in that it uses a renewable resource as opposed to using a more energy-intensive concrete wall. However, the life of the building is a matter of concern. In one of industry's promotional manuals the question is asked, "How long will impregnated wood last?" The company responds, "Properly used Chemonite wood provides a construction material that lasts the useful life of the structure." Incredible! The all-weather wood foundation system has been used for twenty years with success, but twenty years is little time in the hoped-for life of a structure. Seventy-five years has been another projection, but that likewise seems of relatively short duration. There are many poorly constructed above-ground stuctures twice as old, and simple Kentucky log cabins, built of Eastern Red Cedar, have lasted four-times that long.

What becomes of the copper arsenate after wood in the building begins to rot? Are we left with a pocket of poisoned soil? Is the situation similar to the organic gardener who, having discovered high lead content in her vegetables, found it was her soil which had been contaminated by the paint peeling from her old farm house? Can we answer these questions before the symptoms are manifest in our children? Questions like these are neatly dodged in printed material from the corporations. Asked, "Is Chemonite lumber safe to handle?", the company brochure states, "Normal hygiene practice of washing and bathing after working should be observed." The careful reader is hardly comforted by these answers which are little more than restatements of the questions asked. That all-weather wood foundations are accepted by all building code authority in the country is hardly a comfort either. The code, originally designed to protect the consumer from ruthless contractors, has become overly influenced by both industry and labor, and has, in many instances,

denied and refuted this original premise through corruption or neglect.

Like many other aspects of underground housing, the risks and rewards of the all-weather wood foundation are not clearly defined. We need more clear and honest information. It is through the efforts of people like Jim Zanetto and his family that we begin to learn the answers to questions like these. The Zanettos are to be commended for working totally in the private sector, funding these studies from their own personal resources to find the answers.

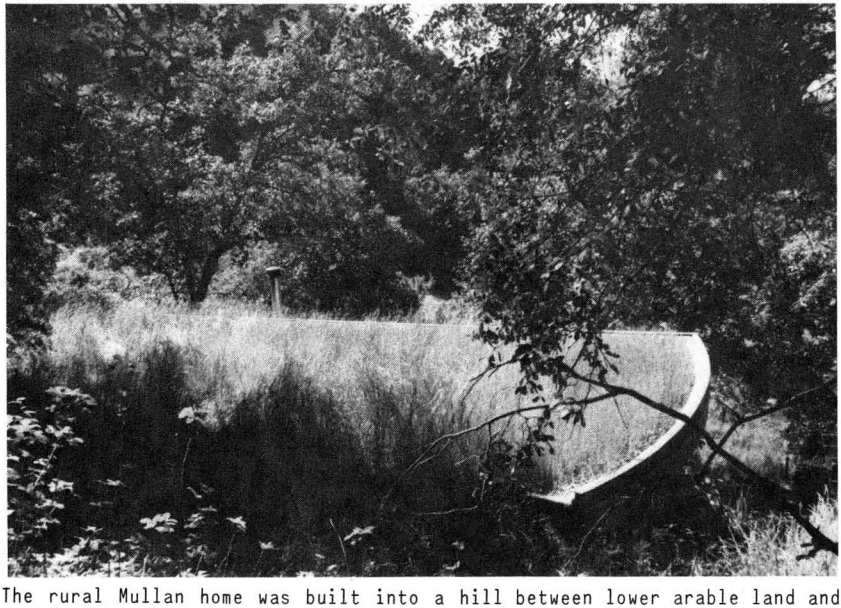
Portions of a discussion with Jim Zanetto.

Otis: Jim, your house seems of a type that could fit the needs of many small families and living groups. Are you willing to sell the working drawings?
Jim: Well, yes and no. What I would like to do is work with the people to fit the house (or a similar, or different house) to the particular site. I'm an architect and I want the finished project to come as close as possible to fitting the user's specific needs and limitations.
Otis: Has your family made any conclusions about living underground?
Jim: Perhaps our most significant finding is that earth sheltered/solar living is very much like living in any other house except that it's more comfortable. The sun comes in when it's cold out, but it's cool and shady in the hot season. Ample daylighting, good cross ventilation are relatively easy to achieve. This is a building type that people of many lifestyles could enjoy. You don't need a commitment to "soft path" living; you just have a soft path house.

To those who would like to use their earth sheltered home as the center of their activities and live as lightly as possible, look closely at the "social environment" of your building site. Live close to your needs (working, shopping, schools, etc.), live within a close community of people, sharing experiences, common land, tools and facilities, and growing as much of your own food as possible. All these situations tend to add an intensity and wholeness to one's life that goes beyond each of the individual aspects.

VISUAL IMPACT OF EARTH SHELTERED HOUSES

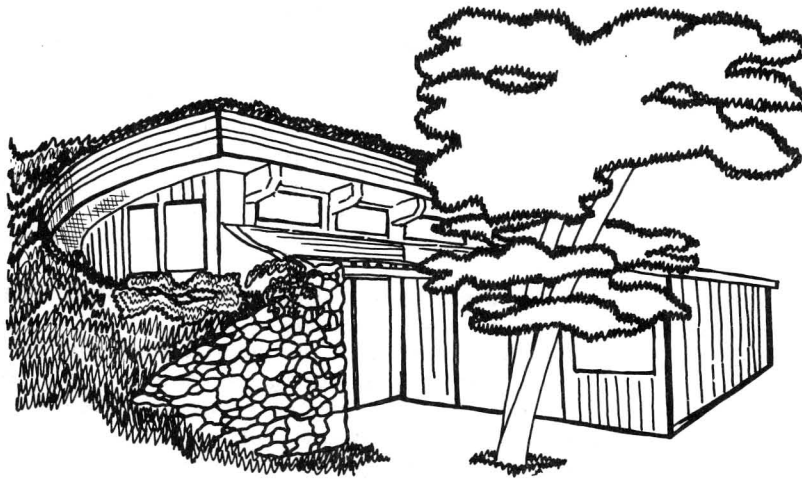
The low profile of the four earth sheltered homes in the foreground contrast sharply with the visual obtrusiveness of the conventionally built houses. Owners benefit by better thermal performance and a roof area which can be productively landscaped.



The rural Mullan home was built into a hill between lower arable land and the woodlot above. The view is from the north.

Chapter 5

The Mullan House



Designing, building, and living underground: the risks and rewards are not yet clearly defined for the owner-builder, but the challenge is there. This chapter describes the design and construction process experienced by our family as we built our underground house and garden space.

Made of homestead logged and milled timbers and slip formed walls supported by reinforced concrete footings and backed with a ferrocement skin, this house exemplifies the owner-builder approach, which combines recycling, low-cost techniques, and experimental construction methods. In our design we included a large greenhouse space for serious food cultivation, a reminder of Forrestiere's intuitive connection between underground living and plant propagation. Our desire to preserve and enrich the environment was our primary motivation for building underground.

DESIGN

Design Objectives. With this as our guiding principle, we formulated design objectives for our house. Over winter months while we logged and milled homestead timber, ideas came together for a house plan.

The promised cool of underground living sounded inviting in our climate where parched summer days often exceed 100 degrees Fahrenheit. To cool effectively, a sod roof need only be deep enough to support green growth, or about eight inches. For winter warmth, a masonry structure, insulated and buffered by earth against heat loss, seemed the perfect combination with a passive solar orientation. Finally, the unobtrusive profile of an underground home would complement the rural setting of the small agricultural community of several families in which we live. We didn't go underground to escape the Bomb or outlive a holocaust: prayer and political action are our solutions to those problems.

As we contemplated our underground house design other objectives also became clear. The house would have to be low-cost and uncomplicated in construction and function, providing compact interior space flexible enough to fulfill the changing needs of family and community. The house would have curvilinear walls for strength and the beauty of an arc-enclosed space.

Building Codes. We decided that to achieve these objectives, we would build without a building code permit. Our technique for slip forming curved walls was not in the code books, our lumber would never see a lumber inspector's stamp, and "going code" would mean great additional expense, from engineering to materials.

To construct affordable homes, many rural owner-builders choose to build without permits, using tehniques and materials unapproved by code authorities. Of course, the elimination of paid labor is the most significant saving of all for the owner-builder; half the cost of conventional housing goes to construction workers. For this reason, building supplies for stud-framed houses are designed specifically to reduce the amount of labor required to put up a building, but their cost is high. In contrast, many owner-builders prefer to lavish their time on labor intensive techniques and use site-available materials, such as cutting and milling lumber, making bricks, slip forming walls, and recycling materials. It's an interesting tradeoff: material costs decrease as the investment in time and labor increase. The nature of the finished product tips the scale in favor of the owner-builder process. Consciously molded by human hands, the house is no longer an unimaginative, spiritless box,

whipped together with a minimum of labor for maximum utility. It is a creation that reflects the temperament, personality, needs and purposes of the building family---special qualities that money cannot buy.

Building codes, however, restrict this type of building, for they are not designed to accomodate the creative owner-builder. None of the techniques that reflect the ingenuity and thrift necessary to homestead are acceptable under the present code. For that matter, few of the homes of those pioneers who built this nation would now be acceptable under the Uniform Building Code. Homestead techniques simply cannot be made "uniform." They respond to the requirements and spontaneous opportunities of specific situations. And while there is a section in most of the commonly-used codes that would allow an inspector to use his or her common sense and good judgment to make on-site determinations of what is "safe and sanitary," this practice is the exception rather than the rule. Inspectors today are, for the most part, hidebound bureaucrats, unable to get in touch with their own common sense or are prevented by their circumstances from using it. No code enforcer will approve an owner-designed-and-built underground house unless the plans are signed by a high-priced architect or engineer. Therefore, many self-confident owner-builders decide to build without compliance to the code. For a complete discussion of this option and more on the code, see The Owner-Builder and the Code by Ken Kern et al.

Preliminary Designs. From these points of departure---the bias for underground living, the freedom from codes, and the desire for a simple yet unique structure---and with the building materials we had accumulated, the design of our house began to emerge. We had a wealth of wood, since twenty-nine trees on the property had died due to invasion by bark beetles. We decided to log and mill this wood for the heavy timber framing on our house. We were interested in using Ken's slip form concrete construction technique that produces a curvilinear wall. The shape was ideally suited to underground building, since the curve would provide the structural integrity necessary to retain great amounts of earth backfill. With those two concepts, timber framing and curvilinear design, we made our first crude model. This gave us a tangible, three dimensional focus for the design work that continued throughout the winter.

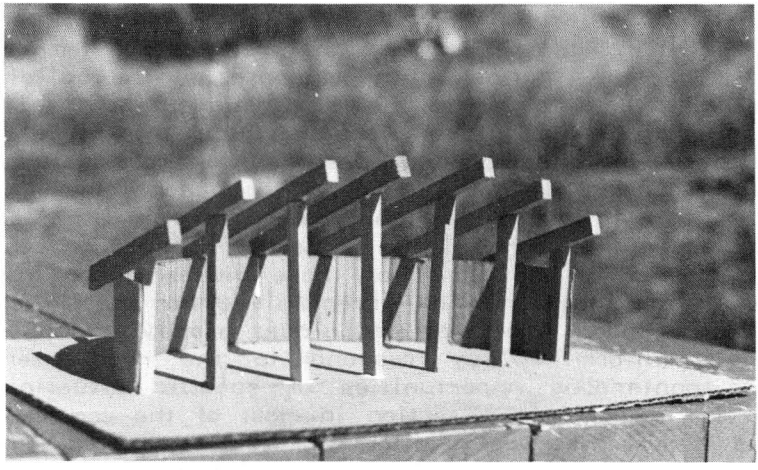


FIGURE 5.1 The first simple model displayed curvilinear wall construction and heavy timber framing. We were better able to visualize details of a plane (wood roof) intersecting a cylinder (concrete walls).

Site Considerations. Early in our deliberations, we needed to select a building site compatible with our design objectives. Our first choice was perched high up on a south-facing hillside, one that had a commanding view. But there was no easy access to it without doing considerable expensive and environmentally destructive road building. The floor of our valley received little winter sun, and we wanted to leave undisturbed its limited amount of tillable soil. We compromised on a site part way up the hillside facing due south, just above the farming land. Located amongst deciduous trees, our site would have readymade summer shade. A ridge to the east was the main imperfection of this location, though this rise of land would limit solar gain only on winter mornings.

Beyond its adequate solar potential, the site had attributes beneficial to building underground. The view to the south, our only view, was beautiful and everchanging, encompassing orchard, pasture, garden, tree nursery, barn, and play yard but excluding sight of other residences and workshops. To the north lay dense woodland, rising steeply behind the house and prohibiting any access. Site soil was red clay, very shallow and underlaid with a stable strata of shattered sedimentary rock, a good base for the

immense weight to be imposed on it by an underground structure. Excess ground water would be no problem since we had chosen a site well above the valley low land, where the water table rises almost to the surface in rainy winters. We did not expect to find aquifers or water-bearing layers of rock during site excavation. All anticipated water run-off would be borne away from the house by means of a French drain running about the perimeter of the structure. Situated on a slope, as we were, this drain could easily be "daylighted," or emptied, below the house with no need to dig a dry well, soakaway, or drainfield.

The most relevant aspect of the location was its being part of a small community, one that included workplace, school, recreation, garden, and friends, all within easy walking distance. The house was not to be a bedroom for a commuting family but a home, part of an active, local community. The fact that we will not do much driving is probably the most significant energy saving aspect of this project, one often overlooked by both suburbanite and the rural single residence builder. Our society needs to change its perceptions and understanding of the relationship between shelter, work, and transportation and how they affect family life, community, and energy consumption. In our small community, we park cars and trucks at the gate and use our feet to cover our own territory.

Model Building. Eventually it was time to relate our simple model with the chosen site. Immediately we detected some problems. To place the single large curve of the house in the steeply sloping hillside would have required too much earth moving. If excavation were minimized, the cost and difficulty of construction might be reduced. Also, a structure built like that of the model would have received inadequate daylight in its interior portion, creating a cavernous atmosphere that we wished to avoid. We concluded that it would be better to build a long shallow building, with easy access to the outside. It would have optimum south wall exposure, better solar gain in winter, and abundant natural ventilation. Finally, with a lot of helpful suggestions from friends, we chose a plan that pleased us. We made a model using supplies at hand: white glue, scraps of styrofoam, sawdust, and white flour paste. It required only two hours to construct, but it cracked with age

because we used cheap materials. However, we did not need an architect's model building skills nor did we want to work with the asbestos-laced model building materials that architects use. Least of all did we need the nasty price tag that architects charge for their model building playtime. Nonetheless, the model was an important tool for designing and visualizing the finished house.

FIGURE 5.2 The second model showed the finalized design in relation to the site.

Interior Design. Many ideas influenced the interior design of our house. We wanted to direct attention outside, through the greenhouse to the garden and tree nursery beyond. We wanted our house to be a natural learning laboratory for our children as they grew, a place where they could learn how the natural world functions each day through the growth of plants and cycles of the sun and moon. We desired a house that would change with the seasons. We wanted our house to be a retreat from the exterior forces of heat, rain, or cold, but still be connected to the outside world. What we sought to achieve with our house design was somewhat like stepping into a cave, where there is an area warmed by fire, but one not so far from the entrance that you lose touch with daylight, fresh air, or the sight of stars and the

moon at night. We wanted a greenhouse space full of plants that could produce a share of our daily food and bear fragrant and beautiful flowers, clean fresh air, and provide extra sleeping space for guests. Through its thin transparent skin, it would be a sheltered spot from which to watch winter storms overhead. Frankly, we wanted a house that would in some way reflect our changing attitudes toward the world. An open, uncluttered place where we could actively work to simplify our lives. When a house is cubicalized into bedrooms, bathrooms, living-dining- and family rooms, a kitchen, study, and laundry ad infinitum, there is a strong tendency for people to accumulate a clutter of material possessions. We wanted a space that, by its limitation in size, would necessarily encourage us to reconsider the few possessions we would choose to keep.

It seemed to us pointless to build a house divided into little boxes each with a separate purpose, each used only at a certain time of the day. To designate a room for sleeping and nothing more is a wasteful extravagence. In contrast, the Japanese store their beds during the day and bring them out only for sleeping. These light beds, called futons, are made of cotton which allows the body to breathe. We chose this type of sleeping mattress for ourselves. By keeping this space uncluttered, the sleeping area of our house can also be used for play and work. Moreover, these beds are easily moved, and we may sleep anywhere inside or out at any time. With this flexibility, the greenhouse has become a family favorite. While our children are small, the family sleeps together. As individually we need more privacy we can easily move the beds!

We also wanted our kitchen to be a flexible multi-use space. We all share in the cooking, baking, and cleaning chores and do not like to be partitioned off like a slave in slave's quarters as we work. Our kitchen would be open to all activities taking place in the home, from greeting and visiting with friends to children playing and people dining, working, relaxing, planting, and harvesting. We live without television: these other things are our entertainment. We provided the kitchen with good storage space, hoping to eliminate those needless trips to town.

The greenhouse was designed to serve many uses. In the planting area, a single large basin would do multiple duty as bathroom lavatory, plant potting

sink, and laundry tray. A tub/shower combination with windows would open onto the planting area with its warmth, light, humidity, and delightful view. Part of the floor space was devoted to permanent plant beds, but the rest was left open to accomodate children's play, relaxing, guest sleeping, or, when provided with movable racks and flats, seedling cultivation in springtime.

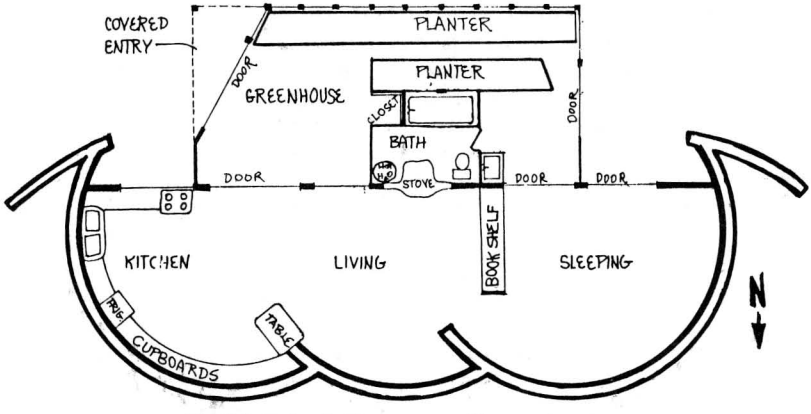


FIGURE 5.3 Mullan house floor plan.

We were pleased with the flexibility of our final design. This house, over the years, could accomodate a single person, couple, or larger family, with never any idle space. Since each area of the house had several functions, less floor space was needed: less to build, heat, cool, clean, and pay for. This would leave us more time and energy to do the life work that is ultimately more important.

Construction Details. The final step in the design process was to work out some of the construction details. Excavation, footing, slab, electrical, and plumbing would be done by conventional method. Support members for roof framing would be contained in the slip formed walls. The roof plan was determined by the size of the beams which could, with practicality, be cut from the timber in our woods. How the beams were to be spaced would be determined by their capacity for safe load bearing. Details for the ferrocement skin and its connections with the structure were planned.

HOMESTEAD LOGGING AND MILLING

The design work and woods work for our project took place simultaneously one fall and winter season. And while details of how we ran our woods operation may seem tangential to the topic of underground house building, we include our experience here for several reasons. Our was to be a low cost house. With usable timber to be found on the homestead, wood was a natural candidate for some of our construction material, particularly for the roof. Cutting our own lumber therefore became one important way to reduce the overall cost of this house.

While we wanted to mill our own logs, we found no source of written information that explained how to do this. So, we offer this account of our experience with the hope that the knowledge we gained may be helpful to other owner-builders contemplating the sawing of their own lumber. All in all, our woods operation was an ecologically and economically successful project, one providing much needed physical activity and respite from lengthy hours of house planning during the long winter.

A survey of the homestead wood lot revealed twentynine dead trees, all standing and suitable for logging and milling. Twenty-eight were Douglas fir and one was sugar pine. These trees measured between 20 and 36 inches in diameter at the "butt," or base. Weakened by two years of drought, they had been killed by bark beetles and needed to be milled immediately to be valuable as lumber.

Scaling the Trees. Rather than hire a professional timber cruiser or estimator to "scale" or calculate the lumber in our trees, we used the composite volume table. Our total yield was estimated to be about 15,000 board feet. This was a large amount of lumber to cut and some of the trees were at remote locations. So we decided it was worthwhile both to invest in a chain saw mill and to hire an operator with a Mobil Dimension Mill, a portable sawmill that is driven to logs in the woods. The bulk of our logs, smaller in size and found in one accessible location, were suitable for milling into lumber up to 4 x 12 in size. Bigger logs of finer quality, destined to be sawn into 8 x 12 beams, could be cut better by the chain saw mill.

Log Scale Volume Table---International Rule, $\frac{1}{4}$-inch kerf

Diameter (in.) Breast High	Number of 16-ft. logs per tree									
	½	1	1½	2	2½	3	3½	4	4½	5
	Volume in Board Feet									
10	17	39	53	68						
12	30	57	80	100	115					
14	42	79	110	140	163	181	205			
16	59	105	147	180	213	247	278	309		
18	74	135	188	235	278	320	360	400	445	490
20	92	170	236	295	350	402	450	499	552	605
22	112	209	290	362	430	494	555	613	676	704
24	133	252	346	431	512	594	665	742	821	900
26	158	300	409	508	604	698	786	880	980	1080
28	187	348	478	597	705	812	918	1025	1137	1250
30	220	408	552	687	911	934	1061	1180	1315	1450
32	256	471	643	794	935	1077	1216	1358	1519	1680
34	292	534	730	900	1060	1222	1380	1538	1724	1910

FIGURE 5.4

Falling. We had had only limited experience falling trees of large size. A friend, who had been a professional faller, spent half a day working with us, teaching falling techniques and cutting fifteen trees in the process. Using much care, it took us two additional days without our friend's help to fall the other fourteen, scattered trees. The conscientious reader may perhaps be able to learn tree falling by reading a manual describing this skill, such as Professional Timber Falling by Douglas Dent. In all situations, tree falling is a dangerous business, not to be approached carelessly. The risks are reflected in insurance rates that are higher than those for most other hazardous tasks.

Snags. Our trees did not qualify as "snags," which are old standing dead timber. These trees are considered the most dangerous to fall, and their wood is not of value for lumber. Our trees still bore dead needles, their fiber had not yet started to deteriorate, and falling them did not differ much in process from falling live trees. Professional tree fallers call snag trees "widow makers," for the vibration produced by pounding wedges into them can sometimes snap limbs high in its upper reaches. As a snag tree comes down, its brittle limbs brushing against other trees may cause branches to splinter and hail downward. Occasionally, once the woodsman has completed cutting

around the base of a snag, all of the bark of the tree may break loose, cascading onto workers below.

Once our trees were on the ground, they were delimbed and "bucked" or cut into appropriate lengths. Big, straight logs were cut into 24-foot 4-inch size, and the rest were sawn into 16-foot 4-inch lengths for use as framing and sheathing material. At this stage of cutting, logs should always be cut a few inches longer than their desired final measurement.

Skidding. Our next task was to find a capable operator with the proper equipment for "skidding" the logs or moving them to the "landing" or milling site. Many of the logs were to be found on very steep slopes in remote locations, making skidding a tricky venture. This operator would have to adapt his methods to a homestead-scaled logging activity. He would have to follow our directions closely, and most importantly, he must know how to do this work with safety. "Setting chokers" or placing cables around logs to drag them out of the woods means working all around these heavy timbers as they are being moved. It is dangerous work. Human life is in the hands of those with whom one works. Select your co-workers with care.

We heard of a local fellow who skidded logs with a team of horses. We tried unsuccessfully to locate him. Others, we knew, had skidded logs with teams of horses or mules to reduce damage to the forest. Half of our logs were perfectly sited for a horse to pull down to a landing site. The remainder, however, had to be pulled up hill, a job not suited to horses which simply cannot pull that amount of weight on an incline.

After several weeks of useless search, we hired a local reputable logging contractor who skidded trees with a tractor. His machine was a D-6 Caterpillar model, equiped with the necessary bull hook and winch and brush blade. He supplied 3/4-inch choker cables, and we supplied the labor to set them. He charged us $45 an hour for his work. Because some of the trees were in scattered locations, he could not give us a price based on the volume of the job.

From the start, we indicated that we were willing to pay for the extra time involved to minimize forest destruction and that we wanted a "clean" job. Cost was not our first concern, since we intended to remain living on this land. Therein lies the difference between commercial and homestead logging operations. The operator we hired was entirely sympathetic with our intentions, which is often the case. Skidding required a

day-and-a-half of work and cost us $480, which is about $25 per thousand board feet of lumber. (Skidding costs for commercial operations usually amount to between $15 and $20 per thousand.) Most of the logs were moved to one accessible landing. Other logs in more remote locations were simply skidded down to an old logging road, where they could be sawn in place by the chain saw mill. We could have saved some money and reduced some of the environmental destruction had we consulted with the skidder prior to bucking our logs. The tractor could easily have pulled 32-foot logs, five at a time, instead of moving 16 footers, five at a time. This would have reduced the number of trips he had to make by half.

Land Reconstruction. Once logs have been skidded to a landing, the full extent of damage to the environment becomes apparent. Logs do as much destruction to a woods as a tractor, so even skidding trees by horse would cause scarring of the landscape. As the rainy season approached, we worked with shovel and grub hoe to repair ridges and troughs left by dragged logs on the forest floor and the skid road. It did not take more than a day for two workers to complete this basic erosion control. For quick stabilization by vigorous root growth, the roadway and bare spots were planted with annual ryegrass. We scattered four types of clover seed to promote nitrogen fixation in the soil and to discover which of these clover prosper in our area. We also threw out a handful or two of wildflower seed collected the previous spring. With this kind of assistance, the wounded hillside recovered rapidly over the winter.

Compare the scene in this photo with any logging operation managed by private corporations or by the Forest Service in your area. Even five years after logging has ceased, skid roads under private or Service management remain barren, eroding gashes in the land. It is decidedly more work to implement environmentally-sound, sustained-yield, well-maintained timber harvesting practices. They will cost more and we will have to pay for them, but the nature of this work is wholesome and healthful, a factor not tallied on any ledger sheet. Humans are not the only creatures who appreciate the special effort made in behalf of forest care. The rye that grew as a result of our planting was grazed extensively by deer. Bird activity flourished about the tall seed stalks. During the following spring, king snakes and rattlesnakes were commonly

seen among the sunny grasses, on the track of a healthy rodent population. It was deeply satisfying to complete this phase of our work with care and respect for the land on which we live. Nurturing the forest strikes a deeply resonating tone inside one's self, a feeling not to be computed on paper or paid out in money.

FIGURE 5.5 Forest damage from skidding logs can be minimized. Erosion was prevented on this skid road by manually smoothing and replanting it soon after use. The photograph shows the skid road six months after logging.

In addition to these measures, we planted trees to compensate for those we had removed. Douglas fir seedlings grew abundantly in this forest so there was no reason to introduce more of this specie: Nature would take her own course. A few cedars were doing well, so we planted an additional five hundred Incense cedar trees. On a different section of slope, one that had previously been damaged by fire many years before and had not regenerated significant tree growth of any kind, we set out five hundred Ponderosa pine. We wanted most of all to put in sugar pine, but in doing related research, we found that commercially raised seedlings are often contaminated with sugar pine rust. Once introduced into a forest environs, this

disease will destroy existing trees as well as seedlings. Sometime in the future, we plan to grow and set out sugar pine seedlings from our own local seed, known by us to be rust free. Each state in the U.S. has a department of forestry, which has information about tree seedlings native to your location. Here in California, the state nursery at Davis is an interesting place to visit.

Milling. Once logs were piled at the landing, their milling began. Two milling methods were employed, the chain saw mill and the Mobil Dimension Mill. Experience had shown us that the chain saw mill was appropriate for cutting lumber of larger dimensions: 4-by and larger. Using a chain saw mill to cut small logs, which were ideally made into lumber of smaller dimensions, required almost the same amount of processing necessary to mill large logs. It takes as much effort to mill each small board as it does to mill a big beam. However, by using a Mobil Dimension Mill, one can cut lumber in all of the smaller dimensions economically and efficiently. Money may be saved by trading lumber to the miller. Those who operate portable saw mills expect to take the lion's share of the milled wook for their services, about 50 to 65 percent. We decided to pay cash for our milling work, at a rate of $150 per thousand board feet.

You may decide to cut all of your own timber with a chain saw mill, but let us give you a word of caution. After we had milled 7000 board feet of lumber, one of the power heads on our saw indicated severe internal damage. Bearings had disintegrated, and because the head was mounted on its side, metal debris soon peppered the internal workings of that motor. The double-ended saw is run with its chain tightened as much as possible. If the chain runs loosely, it will fly out of its channel on the bar. But, operating with a tight chain puts stress on motor bearings, for the two power heads work with each other in force but against each other in tension. Chain saw manufacturers will not warranty a power head used in a milling operation. So there may be unexpected costs involved in your decision to use a chain saw mill for your lumber cutting. It might be preferable, for this reason, to buy two old Mac or Homelite saws, now replaced by lighter and more powerful Swedish and Japanese models, from one of the many older loggers who may still own the monstrous power heads.

Local Woods/Local Skills. There are many uses for

the chain saw mill beyond the production cutting of construction lumber. One of the real advantages of this mill is that it can cut diverse types of local woods. We have chain saw milled three species of local oak wood (now air drying), along with walnut, pear, apple, almond, and olive wood. We also have our eyes on a dying chestnut, an old willow, and a linden, as well as a stand of alder that a neighbor wants to make into firewood. If you have an interest in fine woodworking, a chain saw mill will prove invaluable to you. We may again make woodworking a local endeavor from tree to finished product. Exploitive international economies, which have made the rape of tropical hardwood forests commonplace, will eventually be replaced. As importation of exotic woods for the woodworker has increased, dependence on local sources of fine woods, tools and woodworking skills has declined. Fruit woods are virtually ignored. Here on the west coast, eastern white oak and eastern birch are the woods favored for cabinetry, while our finest Sitka spruce, redwood, and Port Orford cedar are exported to Japan. A wealth of native and introduced species is allowed either to compost or burn in woodstoves. One of the most extraordinary pieces of cabinet work we have seen was milled by a chain saw mill from a walnut tree grown in an orchard in the Central Valley of California. The cabinet's door fronts display the graft, where dark black walnut root stock comingles with lighter English walnut tree stock. For more reading about fine woodworking with chain saw milled woods, see The Fine Art of Cabinetmaking by James Krenov.

Mobil Dimension Milling. Our chain saw mill was used primarily to cut big logs and those to which access was difficult. A portable mill was better used to cut the remaining bulk of our harvest of trees. The mill available to us at the time we decided to log for our house project was a Mobil Dimension Mill. With this saw design, a log rests horizontally beneath a adjustable steel carriage. A saw motor and cutting blades consisting of a Volkswagen engine with an attached 24-inch vertical blade and two attached 6-inch horizontal blades, travels back and forth along the carriage over the stationary log, cutting one board for each pass over the log. This mill, small enough to be carried in the back of a pickup truck, is set up downhill from a log pile. Using a peavey, logs are hand-worked until they roll into place beneath the

carriage. The engine and the cutting blades run back and forth along the carriage, cutting on the forward pass and ejecting a finished board on their return. An operator stacks the board on a stickered lumber pile, readjusts the carriage, and sends the engine and blades on their way again.

FIGURE 5.6 Mobil dimension mill.

The unit we hired was mounted on a 30-foot trailer that transported the mill from site to site, a self-contained one person operation. The operator placed logs on the trailer beneath the carriage, using a loader to do so. He was of the opinion that the primary danger in a milling operation lay in the hand manipulation of logs, a procedure eliminated by use of his loader.

This sawyer, who was milling small amounts of timber for various people, had to move his rig at least once a week. By mounting it on a trailer, he eliminated set up time and the need to charge an extra fee, as was customarily done by other local mill operators. His machinery cut a minimum of two thousand board feet a day, and was much in demand.

Air Drying Wood. The Mobil Dimension Mill cut all of our 2-by and 4-by stock. We stacked and "stickered" 2 x 8s for air drying. That is, each layer of boards was separated an inch from the next layer by three

or four 3/4 x 3/4-inch wooden sticks or "stickers," so that air would freely circulate around every board and beneath each layer in the lumber pile. A rule of thumb is to allow one year of drying for each inch of board thickness, although softer woods, like Douglas fir, dry more quickly, particularly in the scorching hot, dry California summertime. Two-by-eight roof sheathing was air dried to minimize any shrinkage that would become obvious inside the house. The remainder of our lumber was solid stacked, with no particular concern for its need to air dry since Douglas fir cures adequately in place, even in construction, when most other woods will not do so. When stacking lumber, however, make sure that the bottom-most stickers lie in an even plane. If they lie in a curved plane, every piece of green lumber stacked above these pieces will dry with a twist. The best log we selected was cut into 1-1/4-inch boards for cabinet material. It, too, was stacked and stickered to air dry. All of the cabinets in our house were to be made of Douglas fir. This wood is usually considered construction grade wood. For other fine woodworking that can be done with this wood, see pages 86-100 in the book, The Impractical Cabinetmaker, by James Krenov. European woodworkers call Douglas fir "Oregon pine," using it to create furniture pieces of museum quality.

Chain Saw Milling Sequence. The milling sequence we used is shown in the series of photos accompanying this text. The log in the photos was 16 feet 4 inches long and 28 inches in diameter at its butt end. Since this log was felled at the main landing site, the loader there was able to lift it while blocks of wood were placed beneath it to raise it about 8 inches from the ground. This was done only for convenience, for a log is usually sawn where it lies in the dirt.

Stripping Bark. First, bark was stripped away to dislodge any dirt picked up by the log as it was skidded. This step would not have been necessary if the log had been milled where it was felled. Notching the bark every two feet with a chain saw made this work easier. We used two tools: a common ax and a heavy tool called a barking spud. Once commonplace, this old tool can often be found at homestead auctions. Dirt and stones lodged in bark will quickly dull the saw's chain. When thrown outward at random by the high velocity of the chain, this debris can be dangerous to those working in the vicinity. Always think safety.

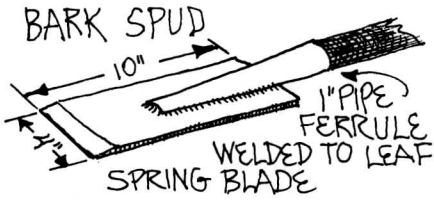


FIGURE 5.7 A barking spud may be homemade by welding a truck leaf spring to a 1-inch pipe.

Safety Gear. The use of safety equipment is a priority for all phases of work in the woods. Ear protection is mandatory. We recommend use of compressable foam ear plugs that re-expand after insertion. Wear heavy boots, long pants, and glasses with safety lenses, for woods work is done on the ground around lots of flying dust and sawdust. A helmet with face screen of fine steel mesh is even better to use. Plastic face guards fog up rapidly and dust settles on this condensation.

Guide Boards. Chain saw milling begins by placing a guide board on top of the log. This board establishes the plane of operation on which the mill will ride. The manufacturer of this machinery suggests using several different rigid guide boards, from aluminum ladders to boards reinforced with steel angle iron. We found that a straight and true 2 x 8 made the simplest, best guide board. It should extend a foot beyond each end of the log. Generally, we used an 18-foot 2 x 8 and took a 2 x 8 x 8-foot-long board with us as an extension for cutting 24-foot logs.

Cutting each log requires a certain strategy. Our priority was for 8 x 12 beams. We also wanted to cut beams of high quality, which meant that, in addition to being relatively free of knots and pitch pockets, the wood would have to be "free of heart center," or as labeled in the lumber industry, F.O.H.C. Lumber containing the heart center is subject to many forces when drying and shrinking and will likely twist. A Norwegian carpenter with whom Otis once apprenticed had a 6" x 16" x 28-foot ridge beam of heart center twist over 100 degrees. Rafters tore loose from this beam, pulling the building apart along its ridge. Against his better judgment, this carpenter had decided to use the only beam of that size that was then available to him, a dead heart center beam. Jacking up a roof, sliding a twisted beam out, and replacing

it with a beam of appropriate fiber formation is a task no builder ever wants to do.

Lumber cutting strategy should therefore be carefully calculated, starting from heart center and measuring up to the edge of the log. Following are some possible cutting lay-outs:

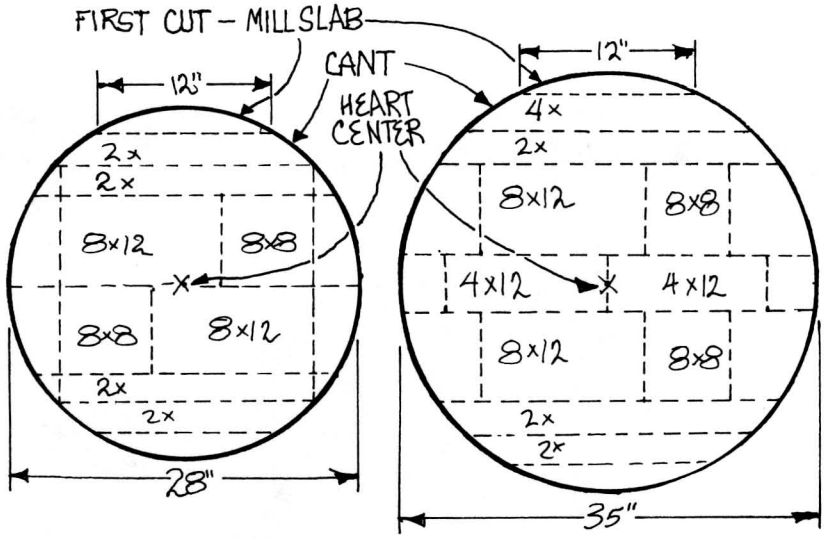


FIGURE 5.8 These log end diagrams show two possible milling strategies. The drawing on the right represents the actual yield of lumber from the log shown in following photographs. The strategy shown in the drawing on the left is superior to that of the former, for large, high quality timbers are then cut even further from the heart center of the tree.

We positioned the guide board, first nailing it to the butt end of the log and measuring the distance from heart center to the guide board. At the small end of the log, before nailing, we shimmed the guide board so that it was the same distance from the heart center as at the other end of the tree. In that way, all cuts would be parallel to the tree's heart center. The guide board was then leveled, by eye or by stretching twine from end to end and using cedar shakes as shims, and was nailed to the log with 20d nails. Every four feet, the guide board had to be supported with shims. If spans were longer, the weight of the saw would depress the guide board, deforming the cutting plane. Any variance in this established

plane will be duplicated in every board cut. Measuring from the center of the log, the first cut was aligned, allowing 3/8 of an inch for the saw kerf. The cut began at least 4-1/2-inches down from the top of the guide board, for the length of a 20d nail is 4 inches, and these nails had to be cleared by the teeth of the chain. The depth of the cut was set on the mill carriage, using calibrated gauges attached to each side of the mill.

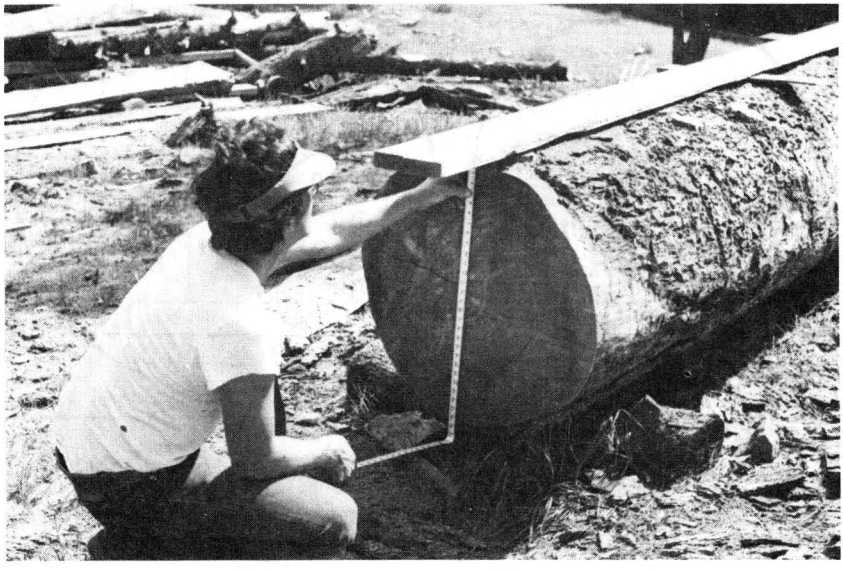


FIGURE 5.9 The guide board determines the plane of the first cut by the chain saw mill. Ends of the guide board were positioned equal distances from heart center. The length of the board was leveled with shims every four feet.

Nuts and bolts on the mill should be securely tightened. Two 100 cc power heads, spinning ten feet of chain, create a lot of vibration. If a nut loosens and the carriage slides, you have to repeat the whole setup procedure to re-establish a plane before beginning to cut again. To prevent this from happening, convert all nuts and bolts on the mill to case hardened ones and carry spares of every part that can jiggle loose.

First Cut. After gauges were set, the chain saw mill was carefully held on the guide board while a cut was started in the log. The whole assembly was

unstable until the bar was fully engaged in the log. When the bar was a foot into the log, a wedge was driven into the kerf to prevent the weight of the cant from pinching the bar. Likewise, as the last foot of cut was approached, wedges were placed behind the saw blade on both sides to hold up the cant while the cut was finished, again preventing the bar from being pinched.

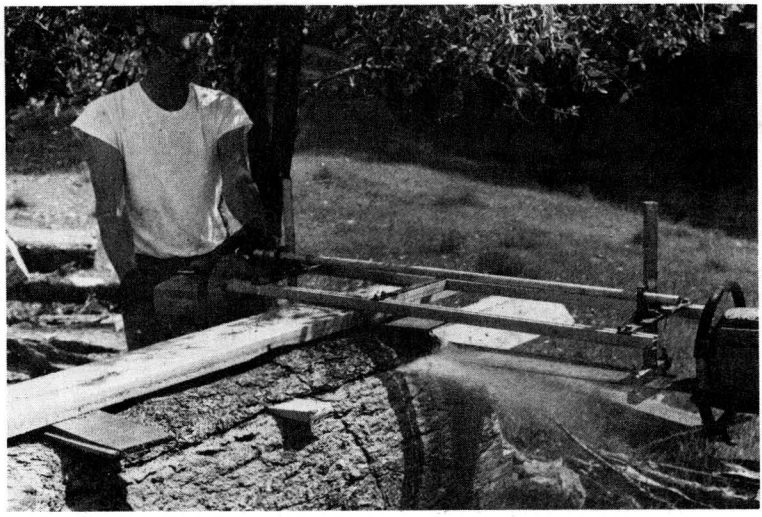


FIGURE 5.10 The chain saw mill carriage rides on the guide board for the first cut, called the mill slab. Note wedge in the kerf to prevent bar from being pinched as the slab is cut free.

During the cutting operation, one power head was drawn up to the log by the pulling action of the chain while the other is pushed away from the cut. The operator of the outer power head had to maintain the level. It was relatively easy to tip the bar out of plane, particularly while cutting narrower cants.

Cutting Cants. The guide board and the product of the first cut, called a mill slab, were set off to one side. The log then had a flat top or plane which was used to guide the carriage on a second cut. The gauges were reset for cutting a 2-inch depth and a second cut was sawn, making a 2-by cant. The gauges were reset to 8 inches and the next two cuts produced 8-by cants. Using a cant hook and a peavey, these heavy cants were slid off the log and stickered. A

peavey is a commonly available log-moving tool, while a cant hook resembles a peavey, although instead of a pike on the end, it has a small claw. Both work well for rolling logs, but the cant hook is superior for moving and flipping cants.

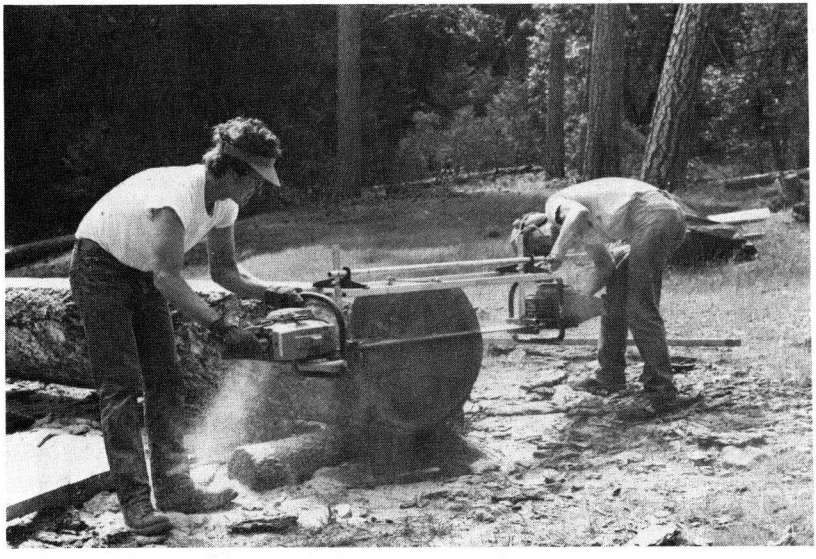


FIGURE 5.11 The chain saw mill carriage rides on the plane made by the mill slab cut. The 8-inch cant being cut in the photo yielded two beams, 8 x 12 x 16-feet and 8 x 8 x 16-feet.

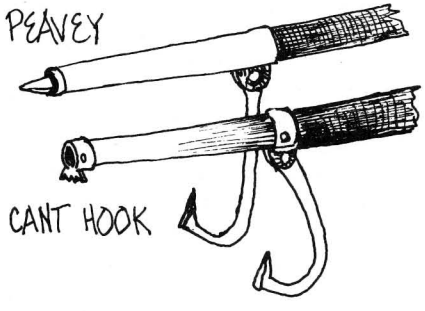


FIGURE 5.12 A peavey and a cant hook are the two tools used to move logs and heavy cants by hand.

The Mini Mill. The cants were then ready for finishing cuts, which were made with a tool called a Mini Mill. This mill is a small saw table that bolts onto a regular chain saw bar. We used a 100 cc power head with an 18-inch bar, although a 14-inch bar would have made the unit more compact, manageable, and safe. A large power head on a small sized bar makes for a powerful, small saw.

The same 2 x 8, used as a guide board during the milling operation, was nailed to the top of a cant. To make a straight cut, the mini mill table rode against the side of the guide board. The Mini Mill table was furnished with a fence, adjustable up to 6 inches. For cutting 8 x 12 beams, the fence was useless, necessitating that the guide board be placed for each cut.

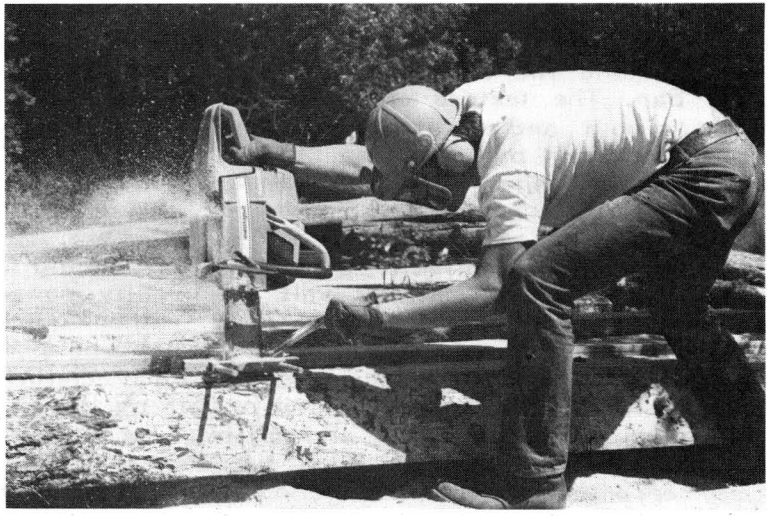


FIGURE 5.13 A Mini Mill is a table and handle affixed to a short bar and chain driven by a large power head. With this tool, one operator makes the vertical cut on an 8-inch cant.

Operation of the Mini Mill was actually a more dangerous procedure than that of the larger chain saw mill. With use of the larger mill, operators pull away from the unit while working. If a person misteps, he or she tends to fall free, away from the unit. To operate a Mini Mill, an operator pushes into

the unit. Any deficiency in the material or a slip of one's hand or foot may spell disaster for that operator, since the force of body and limbs is directed in toward the bar and chain. Fortunately, the Mini Mill is a compact unit and not particularly unwieldy to use. Nonetheless, it should be operated only with the clearest of heads by an operator in healthy physical condition. Satiate work thirst with pure water.

Actually, the Mini Mill can be used to produce boards from small logs. Though slower, it is a one-person operation, suitable for someone interested in sawing fruitwood or other woods for cabinet quality woodworking. Full instructions are included with any mill machinery sold, although claims made by the manufacturer should be subject to sober appraisal. Work with power equipment is always "easier said than done."

Sharpening. Finally, the importance of tool sharpening must be understood. The chain for a big mill has a specifically designed rip chain, consisting of two cutting teeth sharpened at 90 degrees perpendicular to the bar and two cleanout teeth sharpened 20 degrees to the bar. The texture of lumber sawn with a large mill is smooth and pleasing, similar to the "resawn" surface attained by using a large band saw. The chain on the Mini Mill is standard chain, which leaves a more rugged, less pleasing texture on the cut surface of the wood.

Sharpening was a skill we used often during our milling operation. A small 12 volt electrically powered sharpener, run by our truck battery, rather quickly sharpened ten feet of chain. But a hand-held file invariably produced a sharper edge. Each chain is sharpened two or three times during a working day.

Conclusion. Home logging and milling was a rewarding experience for us. Now when we look at a forest, we see opportunity for work (and forest care) everywhere. Subsequent to our logging, we were allowed to remove a standing dead sugar pine from a nearby meadow---free for the hauling. For our efforts, we realized 1200 board feet of clear furniture-grade sugar pine, valued at $1500 per thousand, a profitable day's work. We met a fellow who, to custom mill on site, charges $175 a day for his labor and use of his 48-inch chain saw mill, Mini Mill, and sundry tools. As we learn to manage our forests on a sustained yield basis, small operations like this one will become more and more in demand. As energy resources are

depleted, as tax breaks offered to large logging operations are withdrawn, and as supplies of easily-harvested timber are reduced, these "on site" operations, low in their consumption of energy, will become as economically viable as they are environmentally appropriate. For the owner-builder, the economies of home logging and milling are appropriate right now.

When our woods work was finished, the forest was left undamaged, our muscles were well toned, and many thousands of board feet of high quality lumber awaited a purposeful use. The operation also produced a lot of firewood, sawdust for insulation, mill slabs for barn siding, and bark for mulch. In the end, we owned the tools that would allow us to do this work again. The dollar outlay was less than half the cost of delivered lumber.

EXCAVATION

FIGURE 5.14 The excavation for an underground home should be carefully prepared for and guided by the owner-builder.

According to Paolo Soleri, earth moving "is an ecological undertaking...justifiable if the resulting ecology is better than the original one." It is certainly, in our view, one of the more crucial construction activities involved in building underground housing. Strategies for earth-moving will vary across the country as the type of soil changes with locality. A building's design must be firmly in mind and the builder's committment to its completion must be total, for once this work is begun, the earth lies gashed and wounded. From this point onward, there must be

a clear committment to healing this injury. Many factors enter into this process, and only at the end of your work will you know whether you have created a lasting scar or a garden spot, a strip mine or paradise. The journal entry we made at this moment reads, "awesome, thrilling, and terrifying. Here we are committed."

It is imperative that the underground home builder select a capable machine operator with appropriate earth-moving equipment. The following account illustrates how important this selection may be. Years ago when we built our first house, during excavation for the pad we hired and fired two operators in succession before we learned how to make a proper choice. The fellow we would have liked to do our job was known to work meticulously with a small John Deere crawler tractor, but he was unavailable to meet our time schedule. So we hired a neighbor, a nice enough fellow. Good neighborly politics, too. We had to work elsewhere the day he was to help us, so before we left, together with him we laid out what was to be done and clearly marked all existing water and power lines with a sprinkling of lime. The job required the operator only to excavate for an ordinary house pad. When we returned from work late that day, water was shooting fifteen feet into the air and power to the barn was out. This operator had put his tractor's rippers through both water and power lines, fully ten feet from where he should have been digging, and there were random piles of dirt scattered about the site. We had not know that he was a novice installer of septic tanks who wanted to break into the earth-moving business; he had lied to us about his experience, and had spent two hours practicing on our land. Eventually, he was overwhelmed by his own errors and went home.

The next operator was employed on the basis of an ad he ran in our local newspaper. He charged less than other earth-moving competitors. This time we stayed home to observe work progress. After an hour's work, we had to tell this fellow to go home; he could not control the blade of his machine. This was one of his first jobs, too. Finally we acquired some reliable references but had to wait and pay well for a third operator, who did do a thorough and professional job. Earth-moving is not work for the faint hearted nor is it a task for the careless.

If you do not feel entirely confident about hiring

help, it may be wise to seek advice from others. Ask around your community, from building contractors and landowners, for recommendations for an earth-mover with a reliable reputation. Someone with experience in handling your type of soil will be able to advise you about the size of machine that should be used for your work. Choose an operator who has had experience excavating house pads and basements. Few of them will have had previous experience digging for an underground house. A reputable, experienced operator will charge more money than an unreliable one, but the former will produce more work in the same amount of time and will be well worth the higher hourly price.

The total price for excavation will usually include the cost to transport the earth-mover's equipment to your site. To reduce this cost, while he is on your job you should consider other digging projects for his machine to do, like roadways, pads, or pond work. Neighbors, too, may want to have this type of work done on their places. Like most job contractors, earth-movers will visit your site to give you a free estimate of the cost of work to be done.

Our first choice for excavating our underground house pad was an operator known to be the most qualified and expensive in the area. He estimated that with his small crawler tractor he could prepare our site in about twenty-five hour's time at a cost of $36 an hour. He would, however, be unavailable until six to eight weeks after the time we wished to begin our work. Coincidentally, the homestead community as a group had previously decided to build a swimming pond and water reservoir on a nearby stream, and a much bigger machine would be needed to do this task.

A D-7 Caterpillar tractor, whose operator specialized in pond work for wages at $60 an hour, was chosen. He did a graceful job on our pond, not an easy task with an eleven-foot-wide blade, and amicably followed our instruction and offered us sound advice. An operator's ability to control his machine perfectly and his willingness to be directed by us were essential to the successful, non-stressful excavation of our site. This man, upon learning of our underground house project, showed interest and volunteered the information that before specializing in pond work, he had had years of experience excavating house pads and basements. He looked at our site, estimating that he could do the work in less than a day. We decided that, when the pond work was done, we would have this

fellow cut our house pad. Since this decision was made at the end of a work week, we had an entire weekend in which to finalize our site layout.

Excavation was begun by improving the old logging roadway up to our site and creating adequate drainage away from the house site. Then, in an amazingly short time, with its massive rippers, this earth-moving machine cleared tree stumps from the site. As the economy of using a large-scale machine for this kind of work became obvious, its disadvantages also became apparent. A small clump of three black oak, each six inches in diameter, was to have been saved for western shade. But a small branch of one tree caught in the cage of the tractor as it was working and slapped the operator across the eyes. Two seconds of broken concentration caused these shade trees to be terminally gashed. Power may be efficient, but its control is imperative.

The next step was to push topsoil from the site, piling it above and behind the excavation. Top soil should be saved at all cost, for it is too precious to squander for use as backfill, and with little effort it can be set aside for later landscaping. In any case, humus-laden topsoil is poor quality fill dirt. For the owner-builder, most of the backfilling for an underground house will be done by hand, so bear in mind that it is easier to move dirt down rather than uphill, and provide plenty of fill dirt above the site. When using machinery of this size, everything happens quickly. Directions for even the most basic details of the work may be drowned in the roar of the machine in operation. And at a dollar a minute, the builder in trying to minimize the time spent using the machine, tends to overlook necessary details.

With the topsoil stockpiled, our next move was to excavate soil from the house site. It was difficult to estimate how much earth-moving would be necessary. We tried to visualize the amount necessary to fill holes or to be stored in mounds for later use. In this instance, the eye of the experienced operator became invaluable to us although there was little danger of over-estimating the amount to remove, since creative use could be made of any surplus fill for garden areas, patios, and terracing.

When provision for topsoil and backfill had been made, the earth-moving operation became one of simply cut-and-fill for a house pad. In four-and-one-half hours, this pad was "roughed out." With a machine of

this size, the operator could fairly well detect its levelness. A quick check with a water level showed that the west end of the pad was two inches high, a discrepancy that would have trapped water behind the building. So we requested that the tractor operator make a few more passes with his machine. But in so doing, we easily underestimated the huge amount of material moved by this machine in a single pass. Moments later, the pad was then six inches low on the west end. We figured that it was better low than high in terms of site drainage, but this decision cost us extra work to build a form for a footing which would not have been necessary if the pad had been perfectly level.

Pad excavation involved five, suspenseful hours but cost less than a quarter of the amount estimated for a smaller machine to do the same work. Our conclusion: bigger is not necessarily better but only faster and, in this case, cheaper.

Again, there are as may strategies for site excavation as there are types of soil to move. Soil type in the Sierra foothills varies from knoll to knoll. On this site, the first layer was red clay topsoil a foot to two feet thick followed by shattered sedimentary rock. Thus the base rock of our site was quite stable, and used as backfill, it was of very high quality. Digging it was difficult, however. At eight-foot depth, even the D-7 tractor bounced when using its rippers. A small crawler tractor would have worked endlessly to break up this material. Use of a loader would have been out of the question. Also the slope of the hill was steep enough to prevent most machines from doing this work: it was too steep for either the use of a backhoe or a loader. Thus, the machine that could and did do the work was "the right one for the job."

In loamier soil and on land with less slope, a different earth-moving strategy would have been appropriate. Robert Roy, in his book Underground Houses, describes his choice of loader and backhoe. The bulk of his earth moving was done with a loader, while the sides of the excavation were cleared by a backhoe. In New Mexico, builders of some underground houses also found these two machines most appropriate for their work, although they used them in a different order, first digging the sides of their excavation with a backhoe to get a clean line to dig to, and then using a loader for the remainder of the work.

Firm recommendations for earth-moving strategy are

impossible to give. Soil conditions vary, locating a capable operator with machinery of appropriate capacity for the job may be troublesome, and each earth-moving job for an underground house will be unique. Owner-builders should think soberly that, in choosing to build underground, the stakes are high. The gamble often focuses on the work of site excavation, one of the jobs few owner-builders can do themselves.

BUILDING LAYOUT, FORMS AND FOOTINGS

With excavation complete, our next step was to design and build a slip form, the primary tool to be used for laying out footings and constructing curved walls. An innovative device, the slip form was developed by Ken for owner-builder use.

This small, sheet metal tool is attached to an arm of pipe which rotates about a pole placed at the center point for a circular wall. When used for building layout, it functions much like the pencil end of a drawing compass, scribing an arc for the placement of curvilinear footings and walls. A simple, accurate process, its use eliminates the need for a transit, batter boards, twine, stakes, and a measuring tape and leaves little possibility that a worker may misalign walls---a real bonus for the inexperienced owner-builder.

To build curved walls, the form's cavities are packed with concrete, and the tool is slid forward to its next position. In effect, this procedure forms both brick and mortar, 4 inches of continuous masonry wall that is effortlessly plumbed and leveled. Thus the novice builder can mold a double, curvilinear, concrete wall without the need to build heavy, expensive, wooden forms.

To increase our production, we experimented by building and using a 36-inch-long slip form. (The form used by the Kerns was only 18 inches in length.) However, although we successfully used our slip form to build walls, its added length and weight created problems for us, as discussed later in this chapter. We will describe the device we did build, but we recommend a shorter tool made with materials of lighter weight. Experimentation is the essence of the owner-builder experience, the only way people will arrive at effective low cost building techniques for themselves.

Building the Slip Form. The slip form and its support arm were made of old pipe, a length of chain, and rusty sheet metal. Assembled with an in-

expensive pop riveter, the top and bottom pieces of the form were cut from the flat sheet metal. By swinging a tape in an arc 13 feet from the center point of a circle, we scribed a curve on this metal with an awl. For the sides of the form, we bought a 4 x 4 x 4-inch channel-shaped piece of sheet metal, snipping the top and bottom pieces every 3 inches in order to bend it to the desired curve. The sides were then riveted to the cut-out top and bottom pieces. The ends of these sheet metal boxes were stabilized by inserting 1/2-inch plywood blocks to prevent their racking or stretching apart and filling with concrete. Semi-circular notches were cut in the center panel of the form to permit it to fit snugly against pipes (roof supports) placed between the masonry walls. The finished boxes were then bolted to a 3/4-inch pipe that functioned as the horizontal support arm of the slip form. Our form was easy and inexpensive to build.

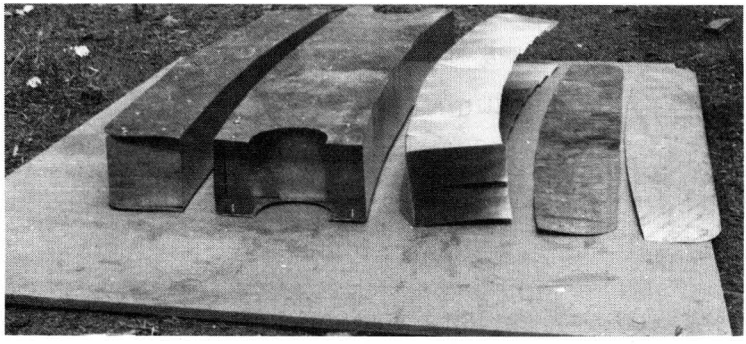


FIGURE 5.15 This photo shows the partly assembled slip form. The side on the right will be finished by pop riveting the flat pieces to the curved channel and inserting plywood blocks in the ends.

A sleeve of 3-inch pipe, 3 feet long, was slipped over a center pole 2-1/2 inches in diameter. At its top, the sleeve was connected to the support arm by a length of chain that kept the arm level, and at its base by a hinge that allowed the form and its arm to be raised up and tied to the center pole out of the way.

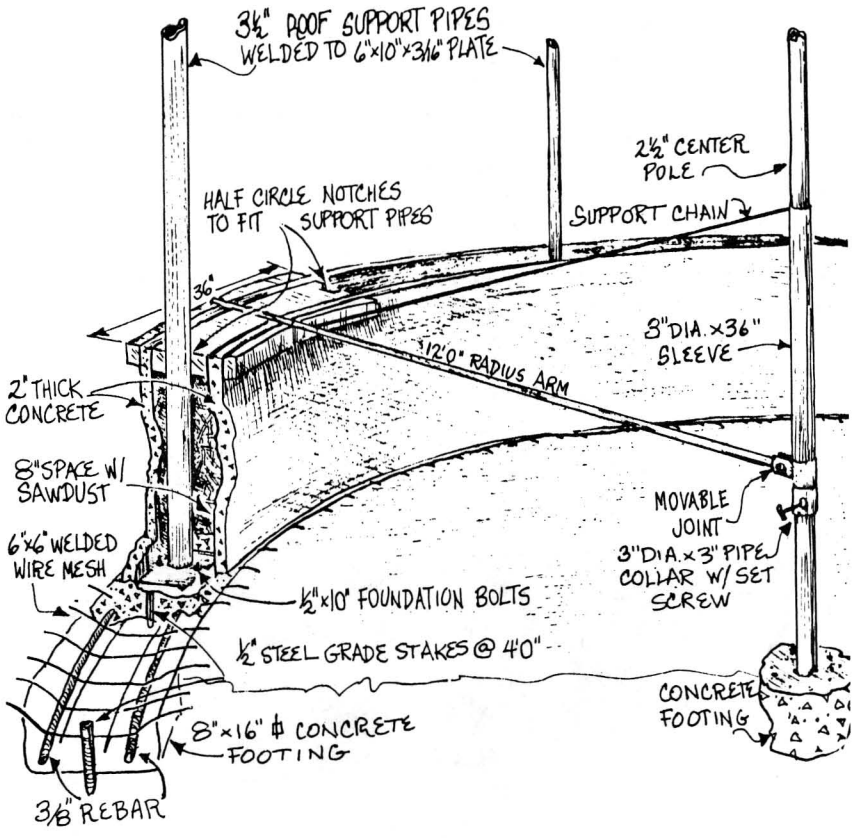


FIGURE 5.16 The double wall slip form system used in the Mullan house.

Placing Center Poles. We then proceeded to erect center poles in order to lay out the footing for the back wall of our house. A minimum of 18 inches was allowed for a space in which to work behind the building. The center points of the structure's circular pods fell along line B, 13 feet from and parallel to line A. Point Y, center point for the middle pod, was positioned mid-distant between the east and west boundaries of the excavation. From this point, we measured 15 feet in either direction along line B to establish the center for each of the other two circles.

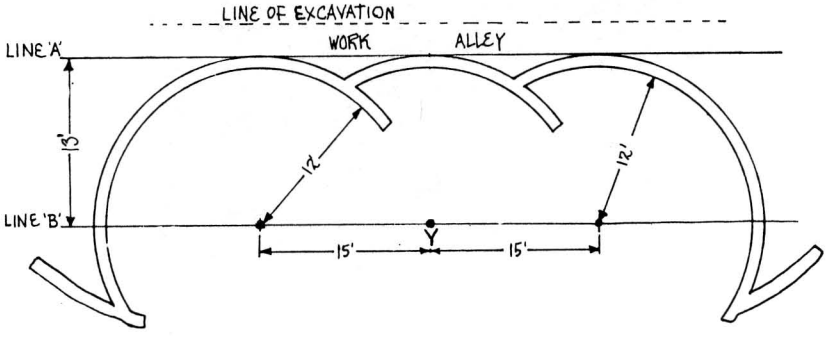


FIGURE 5.17 This simple layout system established placement of center poles.

Center poles 12 feet high were embedded in concrete at the center points of the three pods. They were accurately plumbed and solidly braced while their concrete base cured, or set. Because these poles would guide the slip form during wall construction, any error in their placement, alignment, or erectness would be reflected in finished walls. Layout of footings was the next step in this building process.

During excavation, it was discovered that the finished pad of the house would lie on a stable layer of shattered sedimentary rock, which had a bearing capacity of 8-20 tons per square foot. This was ample for this house, as the weight on any single post would not exceed 5 tons. An 8 x 16-inch footing would therefore be sufficient and construction work proceeded.

Laying Out Walls. The curved wall footing was easily and graphically laid out when lime was poured through the channels of the slip form as it moved along its arc. It was virtually impossible to make an error using this method. A farm tractor with backhoe attachment was used to dig the footing trench. Wooden form work, shown in the photo, was required along the west end of the building. It would have been unnecessary if the excavator had scraped us a level pad, but when grading for drainage, he had taken too much dirt from the west end of the site. A few misguided moments necessitated many hours of extra labor to reconstruct the low spot as well as additional wood with which to build otherwise unneeded form work.

FIGURE 5.18 Marking footings was easily done by pouring lime through the channels of the slip form. Note test section of slip formed wall on right.

FIGURE 5.19 Uneven excavation required wooden forms for the western footing. All materials needed to complete the footings, walls and slab were stockpiled to assure uninterrupted work schedule.

Prior to construction, all materials for the footing, walls, and floor slab were stockpiled in readiness for their use. Where form work was not required, the detailed drawing for the footing was diagrammed in figure 5.17 . Two bars of 1/2-inch steel were placed horizontally in the footing trench. As concrete was poured over them, the bars were jiggled into position by hand, so that they would lie about a third of the distance up into the pour. To connect the masonry wall to the footing, 6 x 6-inch welded wire mesh was embedded in the upper part of the footing pour. This strip of woven wire would eventually tie into a ferrocement shell encasing the outer wall, as well as tying into the floor slab. The slip form was used to score the fresh concrete in order to mark the inner and outer perimeters of the wall, the mesh strips spanning just to the outside of these markings.

Where forms were not needed, 1/2-inch steel grade stakes were pounded every four feet into the soil of the footing trench. A 2 x 4 board was laid level across the top of these stakes, two at a time, showing the proper height to which to pour concrete.

Locating Positions for Roof Beams. The weight of the sod roof was not to be carried by the masonry wall but, instead, was transferred to the building's footings by steel pipes located in the cavity of the wall, one pipe under each roof beam. Two 1/2-inch foundation bolts were placed in the concrete at each roof bearing point. In order to position them, it was necessary to locate placement of the beams. This was done first by placing the middle roof beam, whose center would run directly over the middle center pole, at point Y, and perpendicular to line B, which ran through the three center poles. Using a carpenter's triangle to position this beam perpendicular to this line, we measured 6 feet from point Y along line B to establish point X. By turning an approximate right angle at point Y and estimating placement of line C, we measured 8 feet along line C and found point Z. Line C was adjusted until the distance between X and Z was exactly 10 feet. Line C was then absolutely perpendicular to line A and to line B. To square a corner, builders use the carpenter's triangle, which is basically a Pythagorean triangle, or

$$a^2+b^2=c^2,\quad 6^2+8^2=10^2,\quad 36+64=100$$

A 3-4-5 or 9-12-15 triangle is used as often as the 6-8-10 triangle.

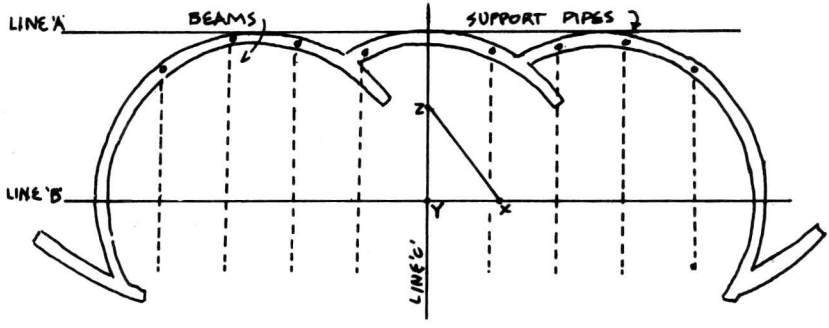


FIGURE 5.20 This layout determined placement of roof beams and pipes that would support them.

Line C was extended and a stake was placed along this line on the far side of the footing. Twine was tied between this stake and the stake at point Y to locate the center line for the middle beam. Measuring out from this string, foundation bolts for the remaining pipe were easily positioned. To assure that bolts would fall within the wall cavity, the slip form was swung over the sites for foundation bolts and the outline of the wall form was scratched into the concrete, eliminating any possibility for error.

Erecting Bearing Pipes. After the building's footings had hardened, bearing pipes were erected. All were of recycled boiler pipe, purchased for less than a dollar per running foot. An 8 x 10-inch flange of recycled 3/16-inch plate steel was welded to the bottom of each of these pipes, their tops allowed to run wild since they would be cut at the proper height once wall construction had been completed.

Before bolting bearing pipes to the footing, their placement along the masonry wall footing was double checked. Using chalk, the slip form was again swung and the wall cavity was scribed on the concrete footing. To ensure that the pipes would be directly under the roof beams, each beam location was measured once again, from the twine line established to mark the center of the middle beam. Accuracy now assured, the flange for the bottom of each pipe was held on top of the foundation bolt. Bolt locations were marked and holes were burned through the flange with a cutting torch. To properly plumb these pipes as they

were bolted in place, other holes were made in the flange and hardened concrete nails were driven through them into the concrete footing to level any high points on the flange.

The footing for the south wall was to be poured later with the floor slab. With this wall area free of construction materials and activity, there was clear access for building the slip form wall. To make certain the cold joint between the masonry wall footing and the slab was adequately strong, four bars of steel were allowed to emerge from the concrete for a distance of 6 feet.

Where the wall of each pod terminated in the house, we built upright end boards that were braced and plumbed. We were ready to begin slip forming walls.

To build walls, the slip form again proved its worth. We were able to construct beautiful curvilinear concrete walls at half the cost of building walls of concrete block. A wall of this type built on-site will become even more cost effective in the future as manufacturing and transportation expense inevitably drives up the price of block. The cavity in the wall provided space in which to run wiring and plumbing, to place structural support pipes, and to carry low cost loose insulation (sawdust from our milling). Actual work was labor intensive but the pace was geared to the owner-builder: slow but steady. It did not require skill, only patience and hard work. It was a forgiving process. From time to time, a fresh layer of wall would slump or lean slightly inward as the form was moved along, but on the next swing past, we could adjust this.

Concrete Mix. The concrete used for the walls contained a mix of 3/8-inch aggregate (pea gravel) and sand. The 3/4-inch gravel mix used for standard concrete was too large an aggregate. Generally called grout mix, the proportion used with cement was 6:1. Concrete was mixed to a very "stiff" consistencey, using the least amount of water possible so that when the concrete was packed into the slip form, the form could be moved along almost immediately without the concrete slumping. Using a minimum amount of water also increased the strength of the concrete. If the mix was too wet, it would slump or tilt or even slip off the **wall after** the form was moved.

In use, our form was too long and heavy to slide effectively. Instead, once it was packed with concrete,

we tapped it lightly on the side with a trowel while lifting it in order to leave the stiff concrete in place. The form was then set down in its next position. This manner of handling was less efficient and somewhat more difficult than sliding the form would have been. The structural bearing pipes were also easy to work around. They fit into the semicircular cut of the center panel in the leading edge of the form which, when packed with concrete, was lifted up, moved over the pipe, and the cut in the following end of the form was placed against the other side of the pipe. This process would be even easier to manage with a lighter form.

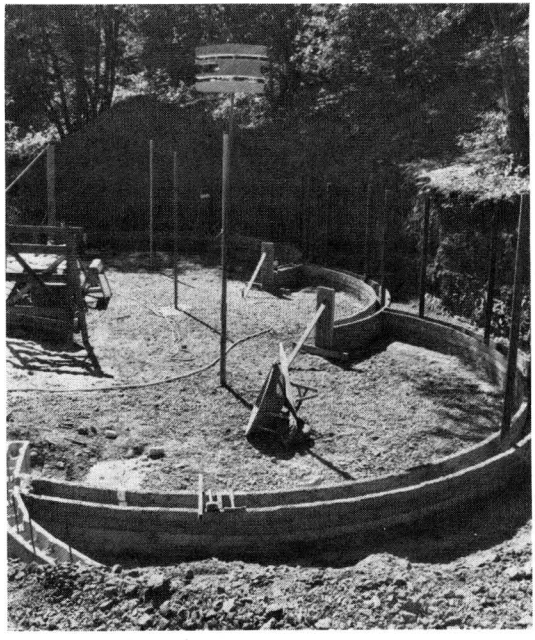


FIGURE 5.21 Bearing poles stand within the slip formed double walls, shown here at 16 inches. Upright end boards are plumbed and braced. The slip form radius arm is raised and tied to the center pole when not in use.

To give added strength to the masonry wall, the bottom 8 inches of the interior cavity were poured solid with concrete. This tactic served to unify all connections between bearing pipe, footing, wall, and slab. Any force working against the bottom of the footing would be transferred throughout the structure to be shared by all of its elements.

Thermal Barrier. At this point in construction, we sought an answer to the problem called "energy nose-bleed" by authors of many of the books on underground housing. The difficulty with many underground masonry structures is the absence of thermal barrier where the wall emerges from inside the home to the outside, as our walls did where they intersected with the south wall. Interior warmth continually perks out of the structure through this uninsulated connection. The resulting cold area of interior wall often has enough temperature differential to form condensation and, during cold weather, to create an unpleasant coolness in that part of the house. Our solution was to slip a piece of 2-inch styrene rigid insulation in the cavity of the slip formed wall where it would join the south wall. To fasten the styrene to the concrete, 16d nails were pushed into the sides of the styrene block. This held it rigidly in place. With every other wall course, a 12-inch piece of 3/8-inch rebar was laid over the styrene block to span this break in the masonry wall. The wood-framed south wall would connect with the masonry slip-formed wall by means of foundation bolts laid horizontally and extending from bond beams in the wall cavity through the styrene into a vertically-placed redwood sill. The inner slip form wall had no weight-bearing capacity, so the styrene thermal barrier could be added to it with no loss of stuctural integrity. Electrical boxes were set into the concrete wall in much the same way. See Figure 5.25

Pouring Bond Beams. With every two-foot rise in wall height, a steel reinforced structural rib, called a bond beam, was poured to strengthen this wall, which was fundamentally a retaining wall. The bond beam also unified the bearing pipes, double wall, and ferrocement shell that would be applied later to the outside of the masonry wall.

To form these bond beams, the wall cavity was first filled with sawdust to within 2 inches of the top of the last course of wall. The sawdust insulation was compacted by walking on it. Pieces of 3/16-inch pencil steel, bent in an "L" shape, were laid across the top of the wall layer at one foot intervals, each piece extending beyond the wall for two inches. The short leg of the "L" was laid on top of the inner layer of wall. These protruding ends would eventually be used to tie the mesh of the ferrocement shell to the outer wall. In the wall cavity, 2 lengths of 3/8-inch rebar was laid across the pencil steel, in the center of the

cavity. The next course of slip-formed wall was laid across the pencil steel and the cavity, with rebar in place on top of the pencil steel, was poured with 4 inches of concrete.

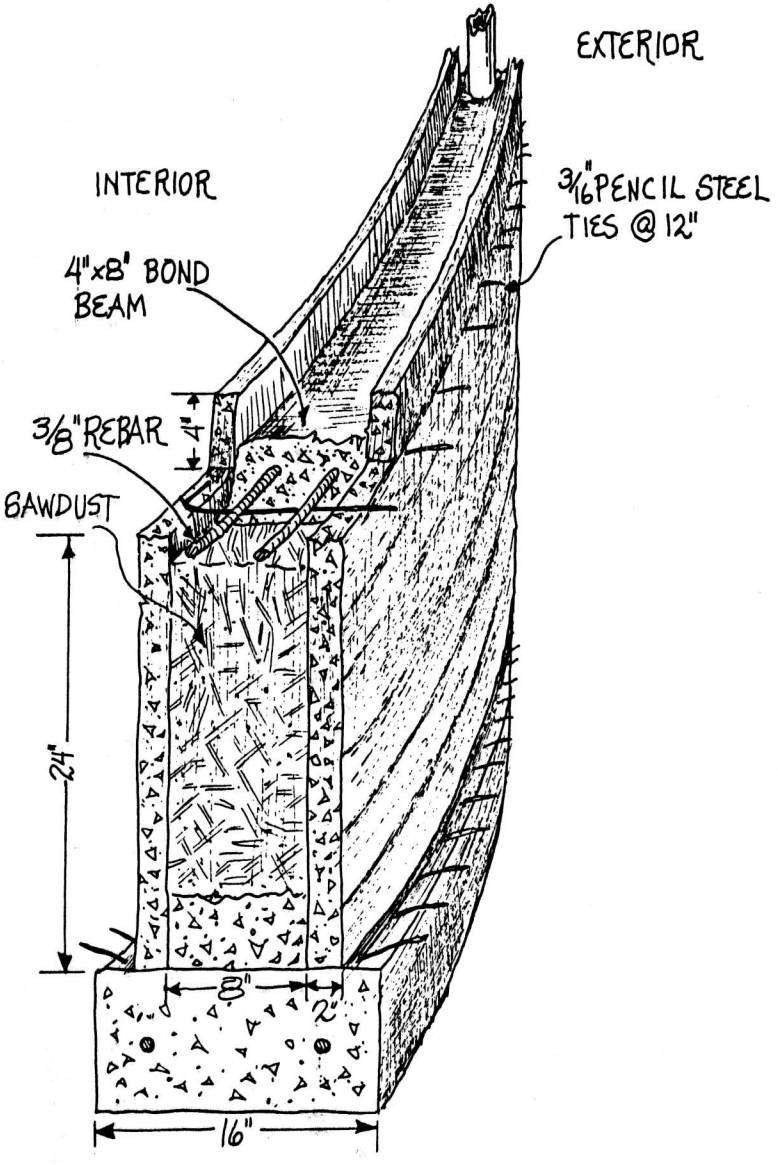


FIGURE 5.22 Footing and wall section. Protruding pencil steel connects exterior ferrocement shell.

Cutting Support Pipes to Height. Determining the height of support pipes in the back wall was not a difficult task. The three pipes at the center back of the building were at the lowest point in the roof system. Each was cut to a length of 76 inches above the slab height. A string was stretched the entire length of the back of the building, in line with these three pipes. The height of other pipes in this curving masonry wall was determined by measuring their distance from this string. Using a roof pitch of 2-1/2 in 12 inches, if a pipe was 20 inches from this line, the calculation for its height would be as follows:

$$2\tfrac{1}{2}/12 = x/20$$
$$12x = 50$$
$$x = 4\text{-}1/6"$$
$$76"+4\text{-}1/6" = 80\text{-}1/6"$$

The slip form wall would now begin to slope upward. With all pipes cut to appropriate height, a 2 x 4 board was placed on top of the two support pipes in the cavity of the curving side walls, and concrete was brought flush with the bottom of this sloping board. At window openings high on east and west walls, foundation bolts were set in the top bond beam.

FIGURE 5.23 To pour the final bond beam, buckets of concrete were carried up the ladder. Support pipes were cut to their proper height. Note styrene thermal barrier where slip formed wall joins south wall.

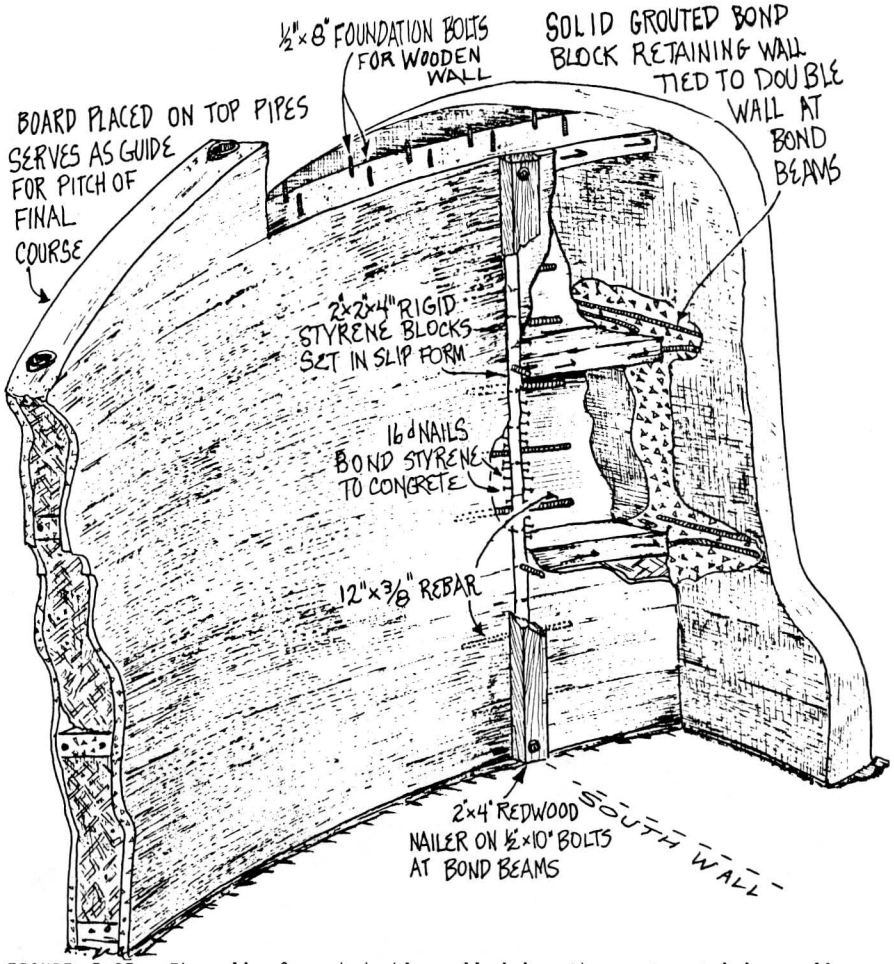

½"×8" FOUNDATION BOLTS FOR WOODEN WALL
SOLID GROUTED BOND BLOCK RETAINING WALL TIED TO DOUBLE WALL AT BOND BEAMS
BOARD PLACED ON TOP PIPES SERVES AS GUIDE FOR PITCH OF FINAL COURSE
2"×2"×4" RIGID STYRENE BLOCKS SET IN SLIP FORM
16d NAILS BOND STYRENE TO CONCRETE
12"×⅜" REBAR
2"×4" REDWOOD NAILER ON ½"×10" BOLTS AT BOND BEAMS
SOUTH WALL

FIGURE 5.25 The slip formed double wall joins the east retaining wall, connecting walls of different construction and the wood roof.

The connection to the wood-framed south wall is accomplished by a redwood sill placed vertically over the styrene thermal barrier. Foundation bolts 1/2 x 10-inches are set horizontally in bond beams every two feet in the wall height.

The concrete block retaining wall joins the slip formed wall at bond beams. The reinforcing steel in the house wall bond beams extends into bond blocks and unifies the two walls.

Wooden walls above the double wall are connected by 1/2 x 8-inch foundation bolts set in the top bond beam. The sill, a 2-inch thick cant, is treated with copper naphthenate and tarred to the concrete with roofing mastic to eliminate air infiltration.

Slip formed walls connect to the wood roof at the pipes and by the ferrocement shell, both detailed later in the text.

Problems. We experienced no major difficulties with building these walls although the work was rigorous. One problem persisted, however, as the top two feet of wall was approached. Our large, heavy slip form became unwieldy when used above shoulder height. Also, as upper courses of wall were reached, the form pulled the center pole out of plumb, causing the top of the wall to lean outward almost an inch. Although this was visually undesirable, structurally it was not a critical matter. The essential difficulty arose when moving the form after it was packed. As the form was lifted and weight on the center pole was relieved, the form tended to be drawn away from the wall toward the center pole. This pulled wet mortar off the layer previously formed and caused the mortar to slump when it again settled into place. This became a discouraging aspect of the work since it was tiring enough just to lift wet mortar to that height. Many wall sections had to be relaid as a result. However, a remedy was eventually discovered. It was necessary to forcefully push outward on the form as it was lifted to compensate for the pull of the center pole. This required considerable effort when done from scaffolding or a ladder. Again, we would recommend a lighter weight form, one that would put less pressure on the center pole and one that could be slipped forward easily, eliminating any necessity to lift it.

Two workers spent ten full days to build these masonry walls. No breaks were taken for that would have left a weak cold joint in the wall. The ten days' work included building a concrete block retaining wall on the east side of the house and insulating the wall cavity with sawdust. This latter activity provided a pleasant interlude for family sharing, one spent happily without having to listen to the incessant drone of the cement mixer. Our two-year-old daughter was filled with enthusiasm for the opportunity to take part in the process. Moving sawdust was a task appropriately scaled to child participation. We also placed electrical outlet boxes in the slip form wall and ran UF electrical wire, suitable for direct burial underground, in the cavity of walls as they were insulated. At the end of ten days, it was time for a much needed rest.

Reflections on Slip Form Walls. This labor intensive system of wall forming will likely never become popular with the commercial building industry. But slip-forming is appropriate technology for the owner-

builder. It utilizes the strength of the curve, offers considerable mass, and provides a convenient cavity in which to run structural support members, insulation, wiring, and plumbing. If a smooth wall finish is preferred, this concrete wall is a perfect texture for receiving plaster, although a more rustic result may be achieved with application of masonry paint. Best of all, curvilinear walls are pleasing to live with and their price is right.

As walls went up, we began the long process of creating something beautiful in the hole we had dug. The house began to acquire personality. Sometimes, it resembled an ancient ruin, an amphitheater perhaps. To our surprise, this wall configuration amplified sounds coming from the valley below and from a distant highway. One evening a skunk wandered from the surrounding woods, perhaps to investigate this new cave happening in her territory.

Creativity and Codes. Building this kind of structure was a unique experiment. Much of the designing and many of the details of construction were responses solely specific to this time and place, to this house. The whole process diverged from that experienced when one builds a conventional house, for which a customary plan is selected and for which familiar building materials are used. An owner-builder must make spontaneous, creative, and courageous decisions. The self-built house may be altered, for example, by a change in one's spirit or by the unexpected discovery of some recyclable building materials. Mistakes take on the quality of discovery. Built in this manner, the owner-built house will be imbued with a special character and will reflect the personality of its origins and its surroundings.

For these reasons, it would be difficult to build this structure "to code." With standardized materials, like concrete block, for example, a host of statistics already exist to make easy any calculations for the strength of a proposed building. When using the slip form wall building technique, the strength of walls depends more on the care and attention given by the builder. Therefore, it is impossible to formulate statistical evidence for such personal and subjective responses and judgments.

The federal government had similar difficulty trying to drum up statistical justification for the legitimacy of adobe construction for Indians living in the Southwest. Again, there were so many variables. How-

ever, the government's need was to include something consistent and constant. It seems that bureaucrats passionately require the fixed and the constant, although these are death-like qualities, and cannot find comfort in the variable, the fluid, or the unknown so often found in life-giving processes. Government agencies ultimately approved adobe for the construction of Indian homes, provided that builders used 1/2-inch rebar every two feet in walls! This incredible resolution was handed down despite the fact that the Pueblos have been standing for over a thousand years. As related by Bill Yanda, the reaction of one Indian oldtimer was to muse, "Well, that's just going to make problems for the archeologists who, in a thousand years, will wonder what all those little red holes in the middle of the adobe were for."

FLOOR SLAB

To complete concrete work for the main building, we needed to pour a footing for the south wall and a slab for the main floor of the house. The south wall footing would lie on rocky substructure that was less uniform in strength than that beneath the north wall footing. This complemented our building design, for the footing of the north wall would actually bear more of the weight of the structure. We decided, nonetheless, to prevent any possibility of uneven settling by building a footing for the south wall that was 16 x 16-inches-wide and contained three bars of half-inch steel. The footing and the slab were to be poured simultaneously, requiring use of only one retaining form.

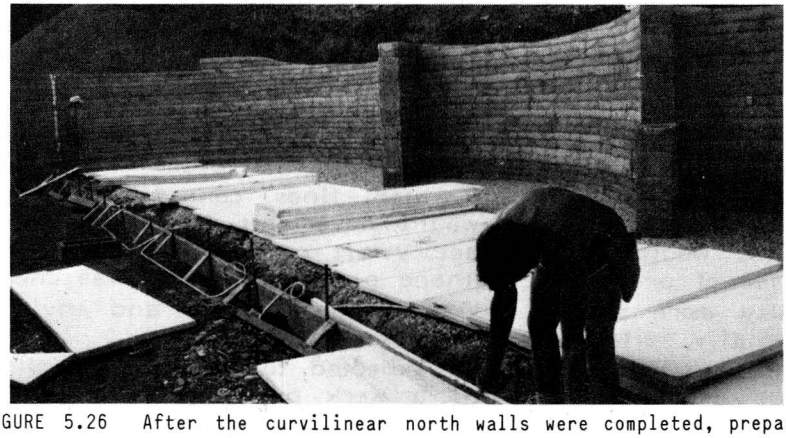


FIGURE 5.26 After the curvilinear north walls were completed, preparations were made to pour the concrete south wall footing and floor slab.

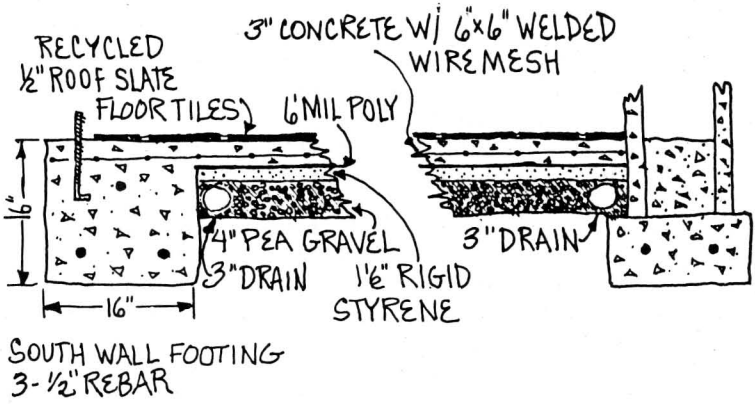


FIGURE 5.27 Cross section of south wall footing and floor slab.

Under Slab Drainage System. To prepare the slab for pouring, four inches of pea gravel size drain rock was leveled over the whole floor area, leaving the footing trench clean. This small aggregate could easily be moved about with a garden rake or a 2 x 4 screed board. Three-inch perforated flexible drain tile was buried in this rock, following the configuration of the perimeter walls. This system of drainage would prevent any hydrostatic pressure from building up below the slab. To waterproof an underground building, we felt the first line of defense should be a properly functioning drainage system. Beneath the floor was obviously the place to begin moisture prevention.

The drain line and water pipes for the kitchen sink were also embedded in the pea gravel drain rock. We used flexible half-inch type L copper piping for water service, which bent and looped easily from fixture to fixture, leaving no soldered joints beneath the concrete floor slab. We wrapped hot water lines with fiberglass insulation held in place with duct tape. Insulating hot water lines conserves energy, and since the lines would never sit in water, fiberglass would be satisfactory. It cost a fraction of the price of premolded urethane pipe insulation, was chemically more stable (hence longer lasting) and environmentally suitable.

Slab Insulation. We expected to insulate our floor slab as well, but until a week prior to the pour, we still had not selected an insulating material. Beneath the slab of a solar house we had previously built, we

had used thick pieces of perimeter insulation but had failed to insulate under the floor slab itself. That floor always felt chilly to us, and based on that experience, we wanted to insulate the next floor slab we built. We wondered if living underground would adequately temper or moderate the temperature of a slab. As a family, we spend a lot of time playing and sitting on the floor, where we wanted to be comfortable. Because any insulation material would be placed on top of the pea gravel drainage material, it would not lie in water. For this reason, it did not matter if the insulation was closed cell (Dow styrofoam) or open cell styrene (beadboard). Open cell styrene will absorb water; closed cell will not. We considered buying but could not locate a source of rigid mineral board, about which we had only read. A nearby Owens-Corning plant manufactured a rigid fiberglass insulation board, but its cost was three-times the price of styrene.

We resolved the question of what type of insulation we would use for our floor slab when we located a man who had over-purchased one-and-one-half-inch-thick styrene beadboard in sheets that were 2 feet by 8 feet. We bought all of his surplus stock at less than a third of the cost of new beadboard. We then had enough styrene to insulate both the floor slab and our exterior slip form walls.

The styrene board was placed over the pea gravel, and a vapor barrier of 6 mil polyethylene plastic was laid on top of the insulation board. Because we were pouring concrete over this soft styrene, we reinforced the concrete floor slab with 6 x 6-inch welded wire mesh. We also placed styrene board along the south wall as perimeter insulation. The south wall was post and beam construction for most of its length so there would be few places in this wall in which to run electrical wiring. So electrical wiring was carried in conduit laid in the footings beneath door and window openings. Switches and plug outlets would be mounted on wall posts. Coursed with three bars of reinforcing steel, electrical conduit, water pipes, waste lines, and drain pipes, the footing became a complicated raceway.

Pouring the Slab. The basic building skill of pouring concrete is adequately covered in many books. Following are some of the things we learned as we hand-mixed our concrete. We placed screed boards only six feet apart, a space easily managed by one person.

Two of us poured the footing and the floor slab in one, fourteen-hour day---a job that should have been done in two, separate days of work. The latter third of this pour had a rough finish, the result of our over-exertion and resultant fatigue. In addition, everyone was too tired to work at all the next day. Little was gained by our over-zealousness, except that the slab was laid. Floor covering should hide the imperfections in floor finish resulting from fatigue and carelessness, so actually little was lost.

FIGURE 5.28 For a hand-poured slab, screed boards should be no more than 6 feet apart.

FRAMING

Once walls and slab were completed, we began construction of the south wall and roof of our building. The change from concrete to wood construction was a welcome one, full of anticipation and excitement. Although we had previously owner-built two homes, this was the first time we would build with lumber of our own making. Heavy roofing timbers had been difficult to manage in the woods, and we knew it would be a challenge to handle them again during the framing process.

Framing Design. Beams were to be spaced 5 feet "on center," that is, from the middle of one beam to the center of the next. Placing a post under each

beam was the easiest and most obvious way to transfer the weight of the roof to the footing. But, in the south wall, we wanted to use some sliding patio doors as well as some recycled glass panels we had purchased, neither of which would have fit had we used posts beneath each beam. Instead, we ran a continuous support member or "header" across the top of the south wall. This gave us more freedom below the header to place glazing (glass) between the large support posts. Above the header, short posts would bridge the expanse between each roof beam and the header, leaving space for clerestory windows. Greenhouse rafters and trellises on the east and west sides of the building would be supported by this continuous header running the full length of the south wall of the building.

Framing for the south wall of the house was somewhat complicated by the enormous weight to be borne by the beams and by certain aesthetic and material constraints. Lumber for this wall had already been cut to 4-by dimension since we preferred a 4-inch-thick wall. A 6 or 8-inch wall would have appeared too heavy and clumsy and would have robbed us of about 15 square feet of indoor living space. A single 4 x 12 header would not, however, have been adequate to span the eight feet needed for sliding doors nor would it bear the weight of two heavy roof beams above. Two 4 x 12s were therefore stacked on top of one another and their splices staggered. Posts would support this header at each splice. To stabilize these framing members, a piece of 2 x 8 lumber would be placed on either side of the 4 x 4 posts, running from the bottom sill to the top of the header. This would be bolted through the six 10 x 1/2-inch bolts with decorative malleable washers. Once these details were decided, we began our wall framing.

Beginning Wall Construction. A 2 x 4 redwood sill was placed along the south wall and bolted to the concrete slab, making sure any splices were located in door spaces where the sill will later be removed. We took a measured length of sill and placed it over the bolts. Next we struck the sill with a hammer at a spot directly above each bolt, thus scoring the underside of the board to locate where holes should be drilled for foundation bolts---a quick, accurate way to measure for bolt hole locations. When the scored sill was flipped over, impressions made by bolts indicated where to drill with a 5/8-inch drill bit. Before

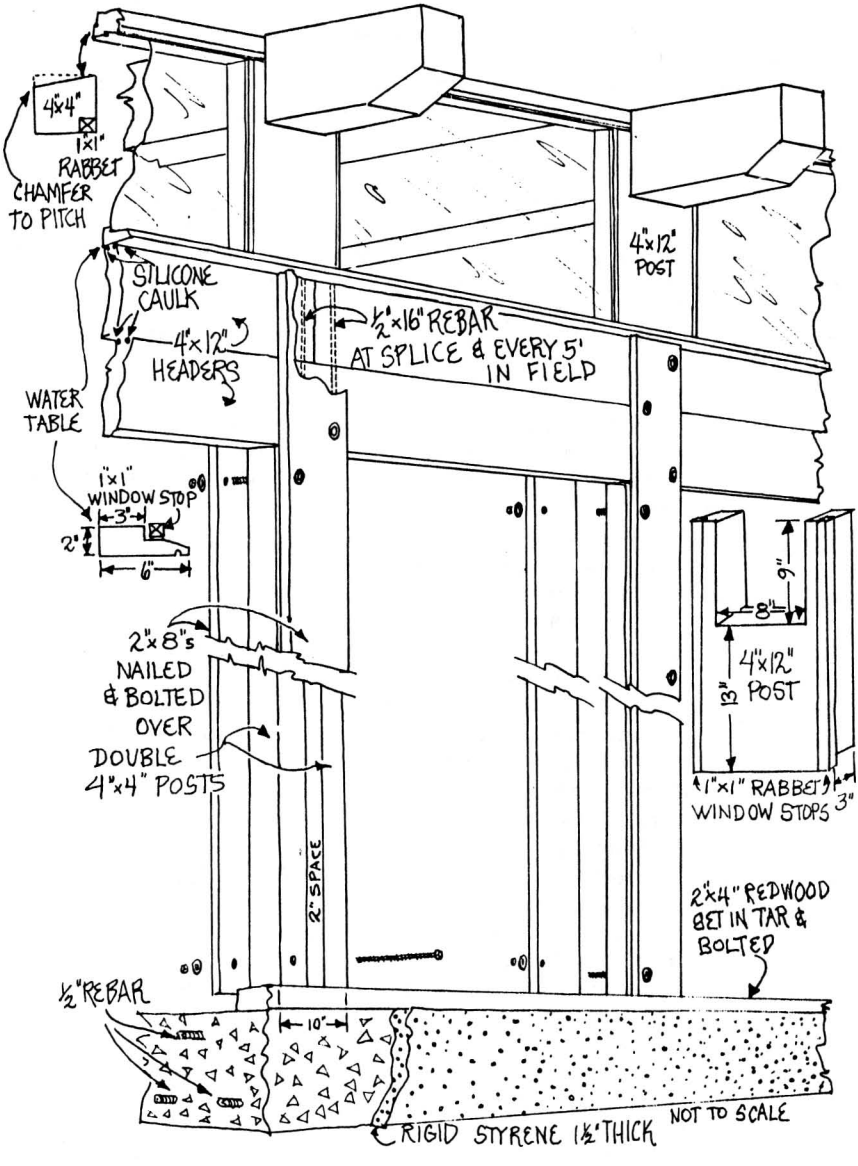


FIGURE 5.29 South wall construction details.

tarring its bottom side, the sill was laid in position once again to make sure of its fit over the foundation bolts. Redrilling or rasping out inaccurately drilled bolt holes after a sill was tarred would ruin tools and dampen spirits. Bedding the sill in tar greatly reduced air infiltration and created an insect barrier for the house. In addition to sills for the south wall, redwood sills were also run vertically up the east and west slip formed walls where they join the south wall. (see figure 5.25) During slip forming, foundation bolts had been embedded in the concrete bond beams of the curvilinear walls. The sills, embedded in tar, were bolted in place.

Sills for the top of the east and west walls required fitting to these 12-inch-thick curvilinear walls. Two-inch-thick cants from the milling process were cut to 8-foot lengths and placed atop foundation bolts already set in the topmost bond beam. As these boards were held in place, they were struck with a hammer to locate where the bolts would fall along its length. Curves of the outside and inside of the wall were scribed on these cants. A 7-inch circular saw blade with a carbide tip was used to cut the curve in this wood. There was just enough extra width in the kerf of this blade to allow cutting the curve without stressing the saw. Had the radius been somewhat less, a circular saw would not have done the work, and the only choice would have been to use a jig saw, a tool that would have taken forever to do the same job.

Posts and Header. The south wall of the house was built with 4 x 4 posts beneath each splice in the stacked header. A 4 x 4 post was also placed flush against the vertical redwood 2 x 4 sills of the east and west walls. Thus the weight of the header would bear on these 4 x 4 end posts, not on the east and west walls themselves. (These curvilinear walls were built solely to retain the earth fill behind them, not to bear the weight of the roof. Only pipes, placed at 5-foot intervals in wall cavities, would transfer roof weight from massive beams to the building's footing.) One benefit of temporarily installing a minimum number of 4 x 4 posts across the south wall was that this provided workers with maximum maneuverability when placing heavy roof timbers. The remainder of wall framing below the header was to be finished after the roof was framed and before the building was back-filled. These posts were temporarily stabilized on either side with diagonal bracing. This bracing should

be adequately strong to prevent accident. Owner-builders often are not aware of the forces involved in the use of heavy timbers, nor do they foresee the potential for disaster. Most carpenters have, at one time or another, seen shoddy bracing give way to cause an accident. As they get older and wiser, these professionals tend to take safety precautions more seriously.

The stacked 4 x 12s which comprised the double header, were fastened by two methods. First, these 4 x 12s were drilled from the top down, using a 16-inch-long by 1/2-inch self-feeding bit. Into these holes, which were the full length of the drill bit deep, 16-inch pieces of 1/2-inch rebar were driven at 5-foot intervals and at a foot on either side of any splice. Next, temporary plywood gussets were nailed with 6d duplex nails to either side of both 4 x 12 headers. When these headers were placed on top of one another, two lines of caulk were laid down, one on the inside and one on the outside edge, to reduce air infiltration. Before 8 x 12 roof beams were set in position, all framing members would be made as stable as possible with bracing. Safety is always a primary consideration.

Placing Roof Beams. Next, we faced the task of lifting roof beams into place. These 8 x 12s were in excess of 20 feet long, except for the two end beams which were 16 feet long, and each beam weighed more than 500 pounds. Two sets of scaffolding were rented for a week, and three strong friends were hired one Saturday to help us move the beams into place. Again, co-workers were selected with care. Concentrated mental and physical effort was required of each person for the duration of this long day. If anyone faltered, a beam might have fallen, crushing whatever lay in its path. The workplace was made as clean as possible, and brew was shelved until the last beam was up and securely in place.

From the milling site in the woods, beams were loaded onto the lumber rack of a pickup. At the house site, beams were slid downhill from this rack onto our shoulders and we carried them to a scaffold. From the scaffold, a beam was lifted, one end at a time, onto a wall, next to its assigned place which was previously marked or "laid out." Each beam was examined for its "crown," which is the arching or bowing of the wood that may be seen while sighting along its edge. As the beam dried, it bowed in one direction or

another when released from compression within the tree. The crown of a board is always placed uppermost to put the strength of the crown's curve in opposition to the weight of the building. A crown of one inch is not uncommon. If you have difficulty seeing it, use twine stretched from end to end to aid your eye.

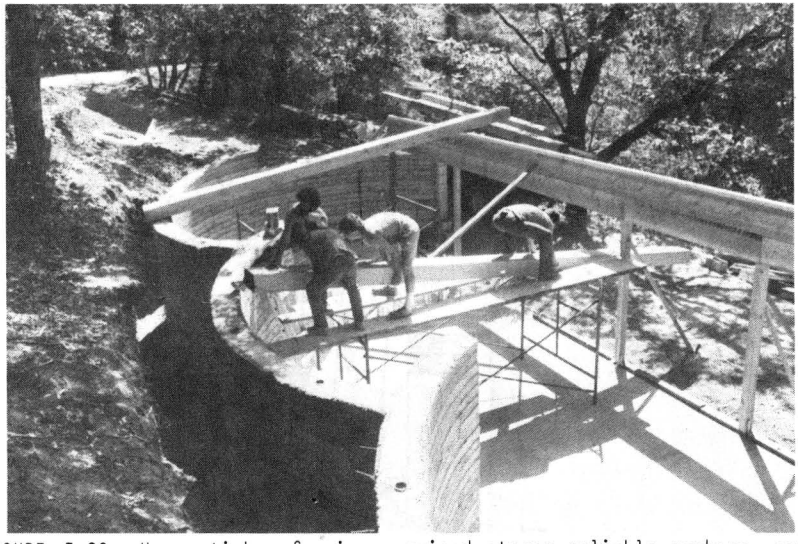


FIGURE 5.30 Heavy timber framing required strong reliable workers, safe scaffolding and an unhurried work pace.

We laid roof beams on the easterly side of their assigned positions, with their crowns facing eastward. The beams were then merely rolled back in one direction to their final resting position.

Short support posts for south wall clerestory windows located above the header were designed to fit the water table. Sawn on a table saw, "ears" on each post would hold in the roof beam and provide a ledge for a 4 x 4 top piece. The drawing shows the entire detail for glazing clerestory windows. To receive glass, rabbets were cut into each post and into each 4 x 4. Each rabbeted cut yielded a 3/4 x 3/4 window stop, which was tacked back into place for safekeeping until the time came to install glass.

Support Pipe Connections. We also designed and built steel brackets to connect the support pipes embedded in the slip form wall with roof beams. We waited until this stage to do this operation, for any

plate or bracket previously attached to the top of these bearing pipes would have interfered with the wall-forming process. A 6-inch length of 3-inch-diameter pipe welded to 1/4-inch-thick steel plate telescoped into the 3 1/2-inch boiler pipe support member. At the bottom of each beam, we sawed an angled cut, called a seat cut. Using four 1/2 x 7-inch lag bolts, we bolted the steel plates to the seat cut. Normally, steel connections are required to be engineered for wind lift, but with 80,000 pounds of sod added to the dead weight of this roof, there was little chance that the connection would lift up and that this roof blow away. The only structural concern was for adequately fastening the bottom of the beam so that it could not "creep" or shear off from a bearing pipe.

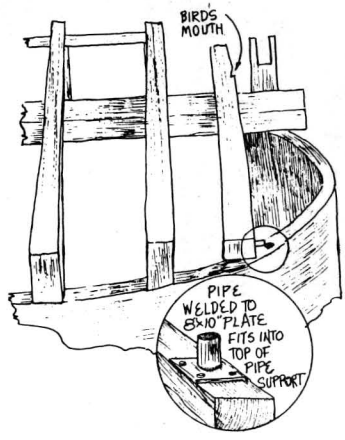


FIGURE 5.31 Support system for beams.

With this steel connector plate in place, short support posts for clerestory windows along the south wall were nailed to the water table, and a measurement was taken from each pipe to the crotch in each post. This length was transferred to the corresponding beam in order to make a "bird's mouth" cut, an angular notch in the bottom of a beam at the place where it will rest on the post. On the two sets of scaffolding a simple tripod was then rigged straddling the first beam. This beam was easily lifted by one person with block and tackle while another person positioned it. With all beams in place, 4 x 4 cross members were nailed between beams onto ears of the posts, completing the clerestory detail and preparing window openings for the installation of glass.

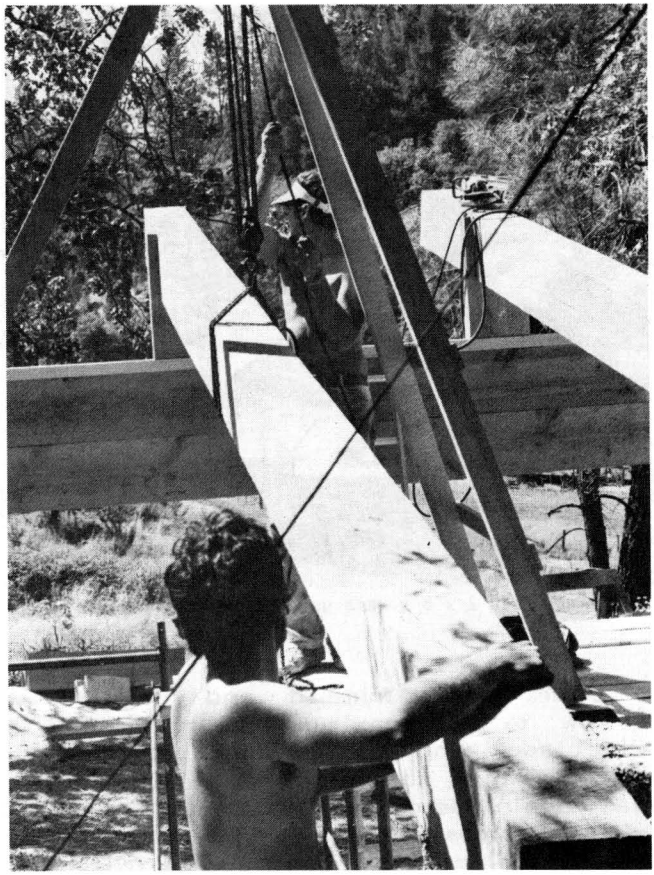


FIGURE 5.32 Once placed on top of the walls, the beams were easily positioned using a block and tackle from a wooden tripod.

Roof Sheathing. Roof sheathing was begun at the upper line of the roof, along the south wall. Normally one would lay roofing boards by beginning at the eave and working up to the peak of the roof, but because the 2 x 8 sheathing we used varied up to three-quarters of an inch per board, we began our sheathing there, at the peak, to insure that it would be parallel to the south wall. This fir sheathing had been stickered for eight months and was dry and hard from the heat of the long California summer. A three-pound sledge, 20d galvanized nails, and a pipe clamp were used to straighten the sheathing and make it lie flat. Even then, some of it misbehaved.

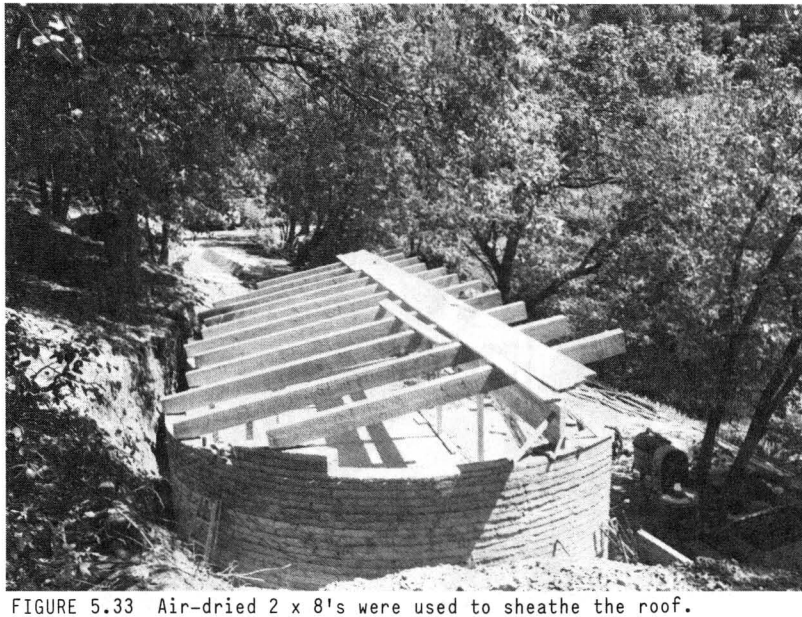


FIGURE 5.33 Air-dried 2 x 8's were used to sheathe the roof.

The beams were trimmed and detailed with a circular saw to the maximum depth allowed by the 7-1/4-inch blade, and the cut was completed with a hand saw. To trim sheathing to a curve, a carbide blade was again used in the circular saw. On the east and west sides of the roof, a problem developed with the sheathing that cantilevered. It had been difficult to make the sheathing lie flat over beams, but here, there was nothing to which to fasten the sheathing. The ends and edges of these boards curled at random. In order to solve this problem, pieces of 4 x 4 lumber were placed above and below the ends of sheathing and clamped together. This forceful "sandwiching" flattened the ends of the sheathing, allowing us to fasten it with 1-inch steel strapping nailed every two inches to the ends of this sheathing. The sheathing laid flat once the 4 x 4s were removed. Fifteen-pound felt was rolled over the top of the sheathing, serving both as vapor barrier and as a black undersurface behind any cracks that might develope between ceiling boards seen from the room below.

Two-by-six joists were then placed on top of the roof sheathing. On east and west sides of the roof, where sheathing and joists would cantilever past the

outer-most roof beam, a 4 x 6 was nailed to each 2 x 6 joist to support the additional weight of the cantilever and to stiffen the roof. Rule of thumb for building a cantilever is stated as: the length of the supporting member should be three-times the distance cantilevered. In this case, the 4 x 6 was cantilevered from 2 to 4 feet beyond the beam and allowed to extend 10 feet on the inside.

FIGURE 5.34 Joist system provided strength for the cantilevered edges of the roof and space for fiberglass insulation valued at R-22.

Insulation and Plywood Sheathing. Two layers of fiberglass insulation (R-11, each 4 inches thick) were laid between roof joists. Fiberglass was chosen in preference to using sawdust both for its ease of installation and its superior performance. All of our site-generated sawdust had previously been used as insulation in our walls, and though we could pick up sawdust for no charge at a mill twenty-five miles away, the cost to transport it offset its advantage. A local lumber company did not charge extra for delivery of the fiberglass along with a unit of plywood roofing. Roof joists were then sheathed with a double layer of 1/2-inch plywood, their joints staggered. Five-eighths-inch tongue-and-groove plywood sheets were not stiff enough where they were spliced to bear 8 inches of sod. Three-quarter-inch tongue-and-groove plywood

would have been too costly. Therefore, two layers of 1/2-inch plywood were glued and nailed into place to complete a solid, well insulated roof.

A layer of 15-pound felt was immediately laid down on the roof to protect the insulation and plywood sheathing from fall rains. The roof was then to be waterproofed and covered with sod, but first the slip form wall required a coat of ferrocement.

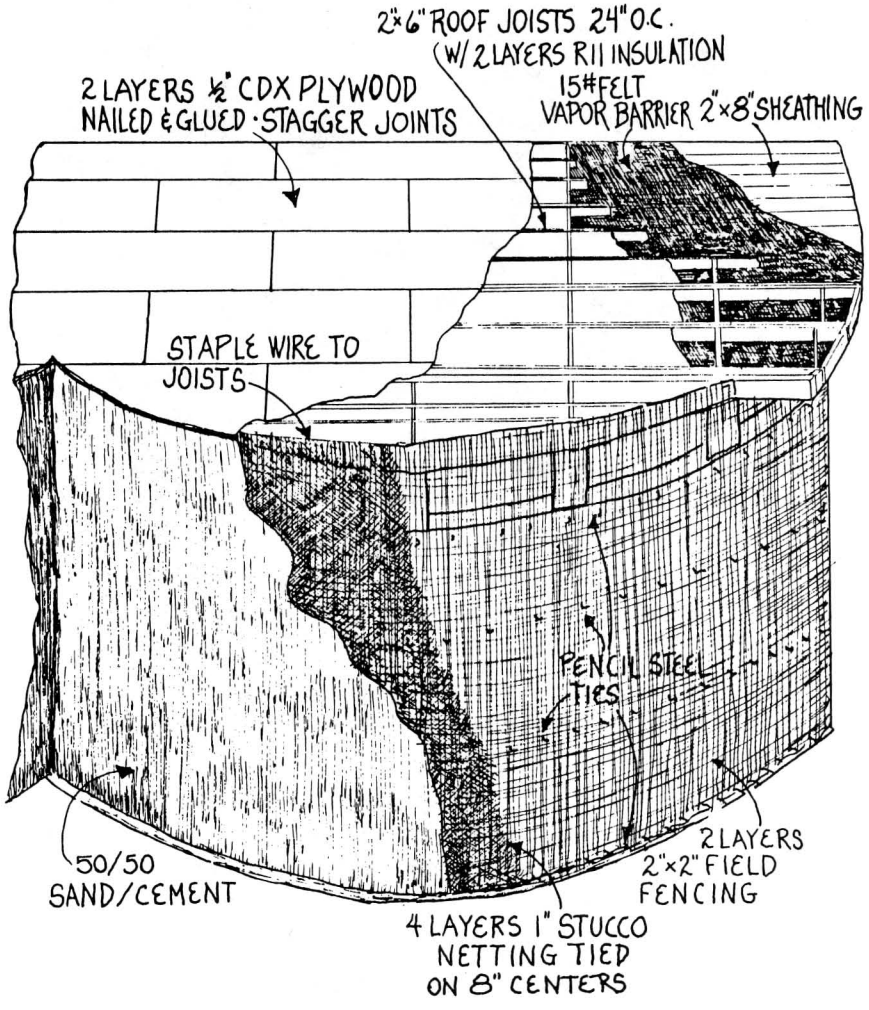


FIGURE 5.35 Western pod construction details as viewed from the north.

FERROCEMENT

Ferrocement, as the name suggests, is a composite material of steel reinforcement embedded in concrete. Using less material than for ordinary poured concrete but achieving similar strength with thin wall construction, its application is labor intensive and readily performed by unskilled labor. Though not widely used in the United States, ferrocement boats, houses, grain storage facilities, and water tanks are gaining popularity in the Third World. It is a technique suited for use by the owner-builder: costs are low and recycled materials commonly found on the homestead may be used.

Ferrocement was applied to our building as a structural skin. It joined footings to the wall and roof systems, creating a marriage of concrete and wood. This shell was, in turn, reinforced by the concrete bond beams within the slip form wall to make a very strong retaining wall that could cope with the forces of earth behind it. That ferrocement is a boatbuilding technique seems particularly appropriate: both underground house and boat must be totally waterproof and structurally strong.

Ferrocement is made by placing layers of steel mesh (welded wire cloth, woven wire cloth, expanded metal lath, or a combination thereof) one on top of another and fastening them together with tie wire. The wire is tied in a close grid pattern, unifying the structure mechanically. A rich mortar of cement and sand is then pressed through the mesh to make a strong thin wall. Ferrocement ships weighing four hundred tons have been built with hulls as thin as 1-3/8 inches.

The only preparation needed on the back wall before we applied a layer of mesh was to cover the wooden rim joists and the ends of beams with tar paper. The first wire mesh we laid up was 2-inch by 2-inch woven fencing. This was applied with some difficulty, because the ends of pencil steel in the bond beams protruded two inches every two feet. But these pencil steel ends, when bent back over the mesh, held it firmly against the slip form wall and unified the mesh with the bond beams. To this base layer, additional mesh was wired: new and used chicken wire, 2 x 2-inch woven wire fencing, and some expanded metal lath along the top of the wall. The type of mesh used was what was available to recycle or what could be purchased cheaply. It was not the

ideal mesh for ferrocement work. We were not, in fact, building something as crucial as the hull of a seagoing vessel. These layers of mesh were fastened with tie wire on an 8-inch by 8-inch grid. The tools we used were lineman's pliers and a homestead-made notched screw driver.

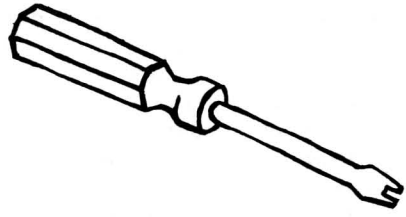


FIGURE 5.36 An inexpensive flat head screwdriver was notched with a file for ferrocement work.

Proportions. The key to successful preparation of ferrocement mortar is in using correct proportions:

1. The ideal amount of mesh is two to three pounds per square foot. For example, this is about 10-12 layers of chicken wire, which weighs 0.2 pounds per square foot. We used somewhat less mesh, or 7-8 layers.
2. For the correct proportion of mesh to mortar, less than 10 percent of the total volume should be mesh. Tie all wire layers tightly together and use just enough mortar to adequately cover the mesh. Recycled wire has irregularities that make a perfect job impossible. Therefore, we used slightly more mortar to mesh then is considered ideal.
3. The proportion of sand to cement is 2 to 1 by weight, not by volume. Simple testing will reveal the proper proportion by volume for your work, inasmuch as the moisture content of sand varies considerably. Sand should be screened 1/8-inch or minus, usually called plaster sand, not the more common 1/4-inch or minus sand, called concrete sand or builder's sand.
4. Another important proportion is that of water to sand and cement. Since it is critical to the strength of the concrete, it is advisable to use as little water as possible. The stiffest mortar that may still be worked into the mesh is considered ideal.

Test Project. Before we undertook ferrocement work on our house, we made a small arched bridge of ferrocement in our garden, just to get a feel for the material and its application. We laid an old piece of 2-feet by 6-feet sheet metal over a bale of straw. We wired 8 layers of old chicken wire together, mixed a wheelbarrow or two of mortar, and in a few hours the project was finished. The experience was invaluable for adjusting the mortar mix and gaining a feel for the work. Wearing rubber gloves, we pushed mud into the mesh by hand. This was easier done than it would have been with a steel trowel. Today, the bridge spans a drainage ditch below the garden, and we learned enough about ferrocement work to have appropriate tools ready for the bigger job at the house.

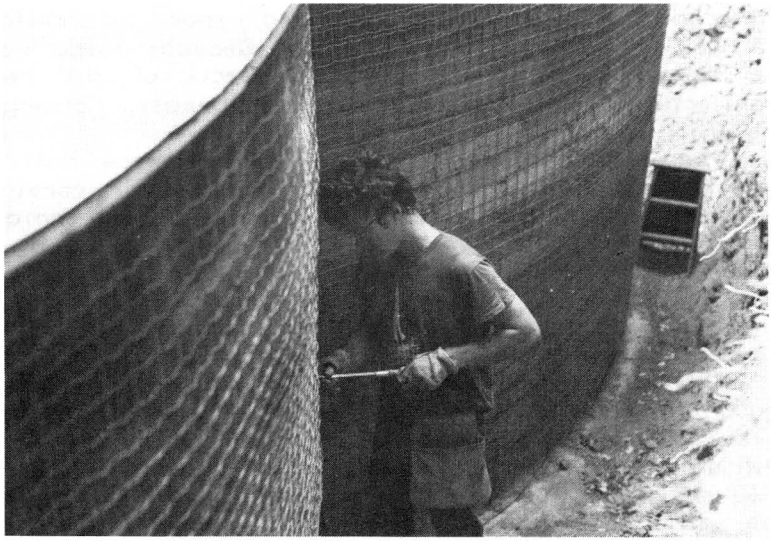


FIGURE 5.37 Outermost structural shell of ferrocement unified footings, wall and roof.

Applying Ferrocement. The wiring of the back walls took several days. Needless to say, it was tedious to work in the narrow 18-inch-wide alleyway behind the house. We hired two friends to help apply mortar, because it had to go on in a single day. To maintain mortar consistency, one person did all of the mixing. With plenty of gloves and buckets on hand, application went smoothly.

The remaining key to successful ferrocement production is in slow even curing of the work. If the weather is sunny, the work should be draped with burlap and sprayed repeatedly with water. Because the ferrocement in this case was in a narrow alley facing north, it received no direct sunlight. Autumn temperatures were mild, and nights were cool---ideal for curing the work. Three sprayings with water daily prevented any cracks from developing along the entire length of the wall. The back wall and roof were now ready for waterproofing.

RETAINING WALLS

As an underground building emerges from the earth, retaining walls are necessary to hold backfill in place. Retaining walls may also be integrated with landscaping, offering a protected spot for delicate plants, and creating patio walls. Because these walls are some of the more visible aspects of the house architecture, they should express beauty, strength, and utility.

The east and west retaining walls were built at their intersection with the south wall. Their construction differed in the materials used and the techniques for building. The wall on the east was built of concrete block, while that on the west was built of river stone, using movable forms developed by Ken. A comparison of these materials and techniques reveals interesting things about owner-building.

The east wall was erected at the same time as house walls. Otis, who was familiar with blocklaying, chose to work with concrete block, which was readily available even though it was not cheap. He found, however, that building a curvilinear wall with block was difficult. Due to the wall's curvature, outside vertical mortar joints were wide, and the mortar in them tended to slump. Unlike building a straight wall where an entire row of block can be laid along a leveled string, each block in this wall had to be leveled and plumbed individually. Any small error made the leveling of block in subsequent courses difficult to do. We wanted the top of the wall to slope gradually downward, but block could only be stepped down. To create an incline, each step-down in the block wall had to be formed with wood and poured solid with concrete.

Even when we achieved the desired slope for the

top of this wall, the structure remained ugly. It needed a coat of plaster. The grey concrete color of the plaster was unappealing, so rather than applying masonry paint we made a slurry of cement and water to which we added masonry coloring. This slurry was 50 percent fine grit blasting sand and 50 percent cement, to which brown iron oxide was added. This color dried lighter in appearance than it had looked during mixing. In retrospect, that block wall was expensive, ugly, and time consuming to build. It had no redeeming characteristics besides adequate strength. Eventually it will be covered with grape vine.

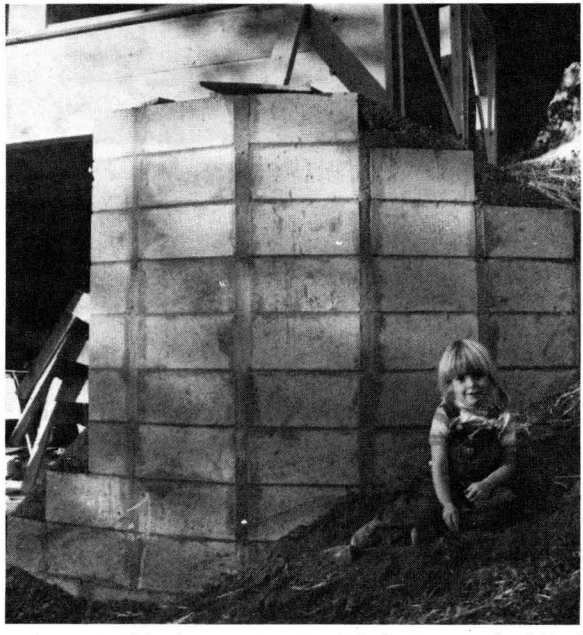


FIGURE 5.38 Concrete block was not a satisfactory material for building curvilinear walls.

Since we needed a clear access to the back of the building for the ferrocement work, we fortunately did not build the west retaining wall at the same time. Jane volunteered to experiment on this retaining wall, building with stone masonry and using Ken's modified Magdiel wall building form. (This form is described in detail in Stone Masonry by Kern, Magers, and Penfield, pages 156-161.)

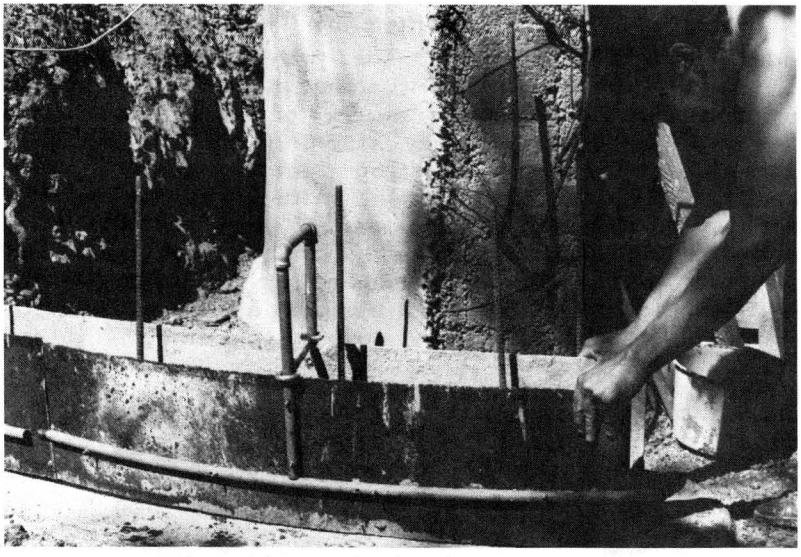


FIGURE 5.39 Movable forms, developed by Ken, were positioned for building west retaining wall.

The process for laying stone in this manner was a little slower than laying block. First, two forms were positioned on top of a footing. Pieces of steel rebar, which rose to the full height of the wall, were wired to rebar protruding from the footing. To build the wall, stone was simply laid against the front face of the form. Any void behind the stone was filled with concrete. In a short time, after the concrete was set, the forms were released by loosening a turnbuckle and moved to the position for a next course. This was done while the concrete was still green. Excess mortar was struck (removed) from the stone face of the wall. A rich mortar mixture of sand and cement was used to fill (or "point") joints between the stones. The top of the wall was easily sloped for only part of the form was filled as final courses were laid. The finished wall required no plaster or paint. It was fully as strong as the block retaining wall and was naturally beautiful and fun to build.

We learned some important lessons while building and comparing these walls. Using on-site materials was more creative, productive, and economical in many ways. For the block wall, we spent cash at a local building materials yard. Much fuel was consumed to haul the block from an ugly manufacturing plant in

the valley up the mountain to a local yard. In contrast, the stone for the second wall was gathered during pleasant family visits to the river.

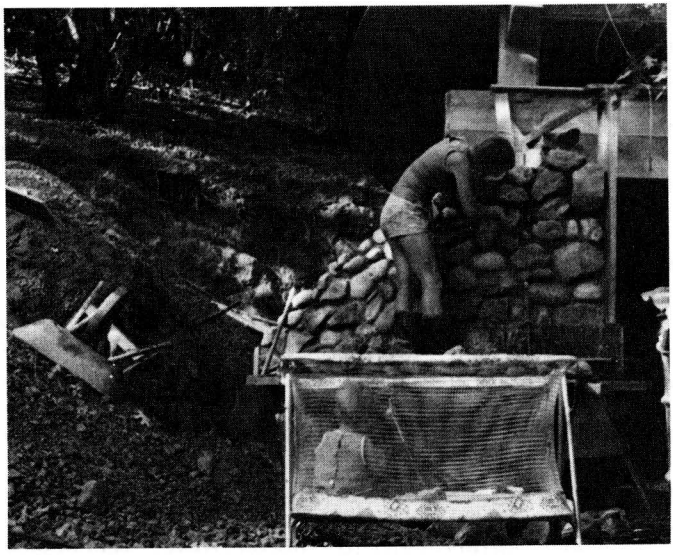


FIGURE 5.40 Stone retaining wall used local materials.

Selecting building materials reflects one's style of living. The dollars spent on the block wall were like votes cast in favor of the complex industrial system that produced the block. The use of block is supportive of a highly technological culture, with its inherent waste and sterile aesthetics. On the other hand, stone for the west wall was gleaned locally with little negative ecological impact and relects the simplicity and beauty found at each step along the way.

WATERPROOFING AND BACKFILL

Waterproofing is a matter for serious concern when building underground housing. To live comfortably below ground, without need for costly repairs, requires study, care, and attention to waterproofing techniques. The walls and roof of a structure present separate problems for waterproofing, but our preventive strategy in either case was to create drainage patterns that carried water away from our building. Roof design was pitched to encourage quick run-off. There were no

openings through the roof which might cause leaks. Similarly, the best way to effectively waterproof vertical surfaces of the building was to prevent water from ever reaching the walls. To accomplish this, we installed a French drain, a trench which carries perforated drain pipe and over which 1-1/2 to 3-inch drain rock is backfilled. Ground water reaches this trench, falls through the rock, and is carried off by the drain pipe. For centuries, this method of drainage was used by the French to remove excess water from low-lying agricultural fields. The drain relieves any buildup of hydrostatic pressure behind an underground building, and therefore relieves pressure on the other waterproofing materials.

Appropriate for Owner-Builder. Horizontal and vertical surfaces of our building differed by nature, design, and the materials of their construction, but we nevertheless applied similar principles when selecting waterproofing material for each surface. Namely, the waterproofing agent must be readily available, easy for the ownerbuilder to apply, inexpensive, long-lasting, and non-toxic.

Waterproofing Walls. The strategy for waterproofing curving walls was to successively layer a series of low cost waterproofing materials: ferrocement, a cement-based waterproofing plaster, a coating of bentonite, and two layers of 6 mil polyethylene vapor barrier. Each provided a layer of reassurance.

The first layer applied to this rear wall was ferrocement. The mortar for this surfacing was made rich and dense. With the large amount of reinforcing mesh used in this layer, this surface should never acquire more than a hairline crack. Two coatings of cementatious waterproofing (brand named Thoroseal) were applied over the ferrocement. This slurry was applied using a floor broom with a 4-foot handle. It went on easily in a couple of hours. The combination of ferrocement plus the cementatious slurry provided a totally waterproof barrier---except where cracks might develope. For this almost certain eventuality, a waterproofing agent with the capability of resealing itself was needed.

Applying Bentonite. Bentonite, a waterproofer with that characteristic, was applied next. This substance occurs naturally and is a highly absorbent, expansive clay that will not degrade. It is rapidly becoming a popular, dependable waterproofing product for underground construction and is commercially available to

the owner-builder in panel form or as a trowel-applied paste at a cost of $1 per square foot. Had these products been less expensive and locally available, we would have bought them. But it seemed a high price to pay for refined clay. We found that powdered bentonite was widely used to seal ponds and was available from suppliers of industrial minerals in 100-pound bags for $120 per ton. Experimentation revealed that, when this form of bentonite was mixed with water and applied to a wall, it dried, cracked, and failed to adhere. But when 6 mil plastic was embedded in a paste of bentonite immediately after its application, the paste stayed moist for at least a week, adhering well to both wall and plastic. In actualy practice, this allowed us enough time to plaster the ferrocement with bentonite, embed the plastic, place polystyrene insulation panels against the wall, drape another layer of 6 mil vapor barrier over the styrene boards, and backfill with earth---before the bentonite could dry and peel from the wall. The weight of backfill against the styrene would hold the bentonite firmly in place, even if it should dry and crack. This configuration of materials was recommended by a manufacturer of bentonite paste, although their product did not require that plastic be embedded in it. All manufacturers of bentonite advise that their product is water soluble and must not be exposed to rain.

Prior to application of bentonite paste, the edge of the roof was coated with fibered roof cement, reinforced with 6-inch fiberglass cloth. This sealed the first layer of 15-pound roofing felt onto the Thoroseal ed ferrocement wall.

Then, a half-inch of bentonite plaster was applied with a trowel, from the footing to the tarred edge of the roof. Plaster was mixed in buckets with a device of our own design. We welded 6-inches of chain to one end of a piece of 3/8-inch rebar, 30-inches long. Inserted in a variable speed drill, this was perfect for mixing plaster in a bucket. We used the same device earlier to mix the Thoroseal.

Once the bentonite plaster coat was applied, a six mil polyethylene vapor barrier was immediately embedded in it. The plastic was stretched tightly and air bubbles were forced from beneath the sheet. This sheet was carried up over the edge of the roof for at least a foot. Styrene insulation boards were then placed along the wall, up against the plastic, to protect the bentonite and the plastic during backfilling

operations. Then another layer of 6 mil plastic was draped over the styrene. This sheet, too, was carried up over the roof at least a foot. A layer of 15-pound roofing was unrolled onto roof sheathing, covering ends of the plastic to protect them during backfilling. Edges of the roof were then coated with another layer of fibered roof cement that was reinforced with 6-inch fiberglass.

FIGURE 5.41 Six mil polyethylene was pressed into wet bentonite plaster, which had been applied to Thorosealed ferrocement wall.

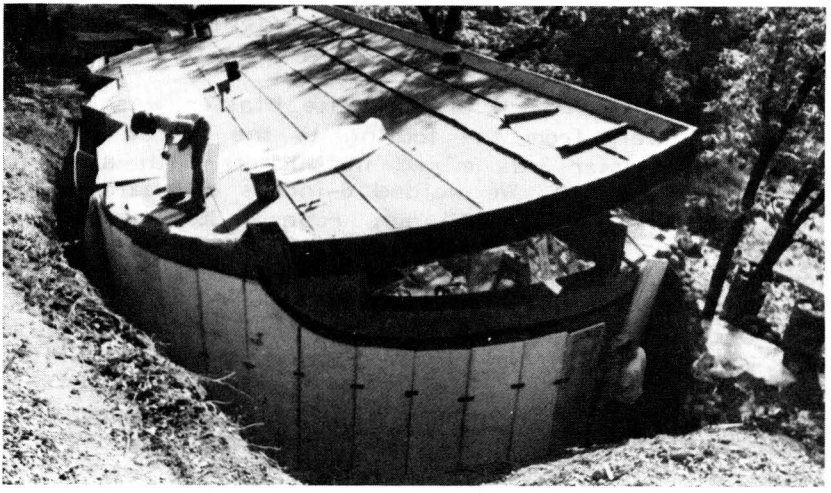


FIGURE 5.42 Rigid styrene insulation boards protected the polyethylene and bentonite layers during backfill.

French Drain. Having completed waterproofing of the walls, we installed a French drain in the space between the soil of the hillside and the back wall of our building. This drain would be composed of drain rock (1-1/2 to 3-inches) placed directly against the full height of the wall. This very porous layer would quickly carry any water reaching the building down to the perforated pipe system at the footing. However, the work alley behind our house was at least 18-inches wide, and sometimes more, and to fill this entire cavity with drain rock would have been grossly expensive. We needed a cheap material in sheet form to separate the necessary six inches of drain rock from the soil used to backfill the remaining space in the work alley.

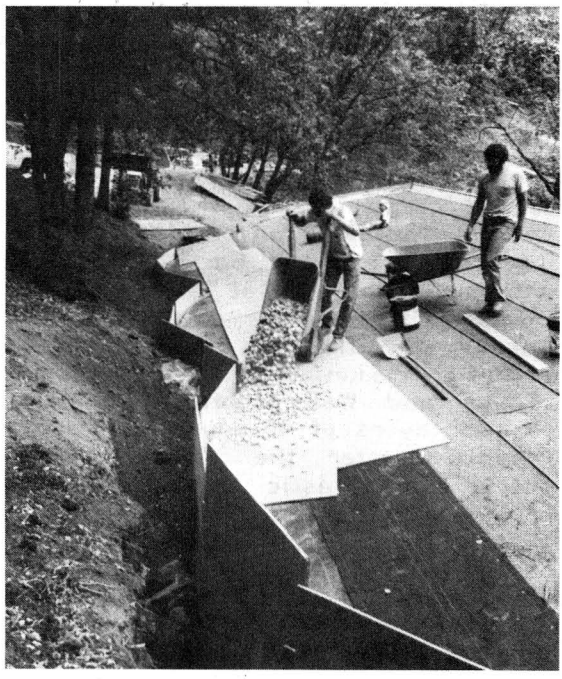


FIGURE 5.43 Rock for the French drain and dirt backfill were separated by inexpensive particle board.

At a lumber yard specializing in purchases of surplus materials, we found a pile of old particle board. These sheets, measuring 5-feet by 19-feet by 7/8-inches, cost $5 a piece. They were high-density,

furniture grade quality. Below the first half dozen sheets, the boards showed signs of abuse only along their edges. We bought the stack, had enough sheets to separate rock from soil during backfilling, and saved the best of them to use for interior cabinet making and shelving. One benefit from using aged particle board was that most of the formaldehyde, from glue used in its manufacture, had already outgassed.

The French drain we built by laying 4-inch diameter flexible drain pipe along the footing. Then, sheets of particle board were placed vertically and nailed together along their edges. Rock or fill dirt were shoveled evenly on either side of these sheets. Done by wheelbarrow, backfilling was a slow process, taking a week to accomplish with one hired helper. To expedite backfilling, we worked from the roof, but first we lay plywood down to avoid puncturing the roofing felt. When the cavity behind the rear wall was filled, any particle board retainers that protruded were cut flush with the roof. The top of this drain system was capped-off with three inches of straw to prevent its silting up with soil.

We did not compact the soil used for backfilling, choosing to let nature consolidate those materials. During rainy weather, the backfill was dressed or covered with more soil as it slumped downward. It required three such dressings that first winter, each with six inches of soil. For the ten feet of fill we used, consolidation amounted to 18 inches.

Roof Eaves and Waterproofing. At this time the roof carried two layers of 15-pound asphalt-impregnated felt, one applied after the plywood sheathing, the other to overlap the plastic sheeting brought up from the walls. Both were sealed down over the edge of the roof with fibered roof cement reinforced with fiberglass cloth. A curb was then built on top of this felt, around three sides of the roof to retain a final covering of sod. Across the eave of the south wall, we ran a 2 x 8 rim joist. Triangular blocks were placed against this joist every two feet. Half-inch plywood sheathing was nailed into the block.

For east and west eaves of the roof, this detail was changed slightly to accomodate the curve. The rim joist was excluded and the triangular blocks ran to the very edge of the roof, on 16-inch centers. Short 2 x 8 blocks filled in between the triangular blocks along the edge. These side eaves were sheathed with

half-inch plywood cut into short pieces in order to bend with the curve. The triangular shape of this short parapet wall prevented pressure from the sod roof from forcing the tacia out of line. This entire curbing was then coated with fibered roof cement reinforced with fiberglass cloth. A layer of 30-pound felt was next laid down to cover the roof and the rim curbing. Laps of the felt were sealed with fibered roof cement.

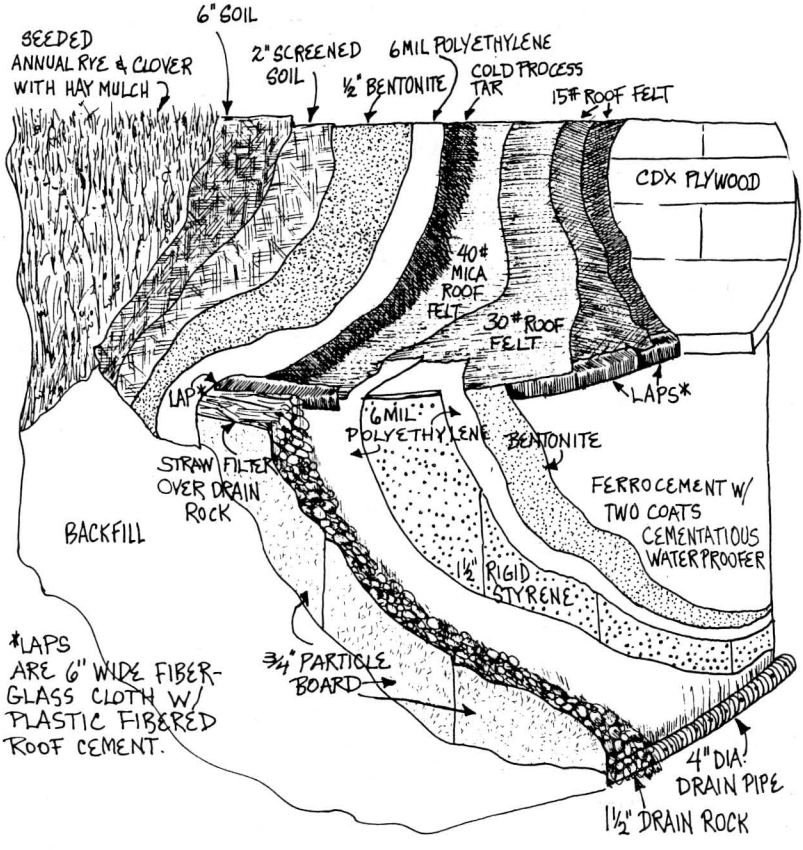


FIGURE 5.44 Western pod waterproofing and backfill details as viewed from the north.

The last layer of roofing felt laid down was 40-pound mica-coated felt. It was sealed at the laps with cement. The entire surface was painted with

liquid cold process tar, and a single sheet of 6 mil plastic 20-feet by 60-feet was bedded in the tar. Mica-coated asphalt-impregnated felt was the only roofing felt that could be used with cold process tar, for other types would have absorbed the tar and would not have held the plastic effectively. Eight-inch wide aluminum roll flashing was nailed over the curbing that retained roof sod.

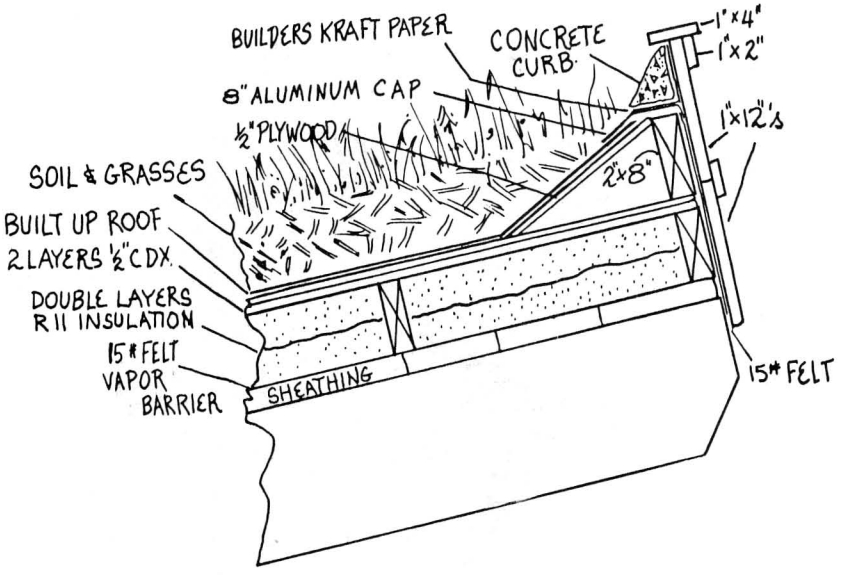


FIGURE 5.45 Facia detail.

Roof Sod. To backfill the roof, a half-inch thickness of dry bentonite was spread over the area. Top soil was screened through 1/2-inch hardware cloth as it was shoveled into a wheelbarrow, and two inches of this screened dressing was carefully sprinkled over the bentonite. The light, dry bentonite was readily moved or blown at this point and care had to be taken not to displace this layer with the dressing of dirt. The two-inch dressing of screened soil was followed by another six inches of soil. This soil base was immediately planted with annual rye grass seed, known to have quick and vigorous root growth. Manure was spread over the soil and the entire roof was mulched with straw to break the force of rain drips until the rye grass sprouted.

Questions and Results. Waterproofing was one of the most experimental aspects of building this house. Because there have been no long term tests for the host of new products flooding the market in this field, we relied primarily on architectural design and use of proven long-lasting building materials: from the unified moisture barrier from facia to footing backed by a full height French drain, to the skin of the structure composed of cement and bentonite. We felt polyethylene plastic and built-up asphalt materials would have limited life expectancy underground and considered them only as "back-up" material for waterproofing.

Some question remains about the effect that plant roots may have on bentonite. If roots penetrate bentonite, its capacity to reseal will be destroyed. When polyethylene breaks down, as inevitably it will (recent studies indicate that this plastic breaks down even beneath soil, and the Forest Products Laboratory indicates that it is not an absolute barrier anyway), the asphalt built-up roof will be exposed to moisture. Asphalt is slowly water soluble underground, and may be subject to breakdown by organic acids from roots. When exposed to moisture, felt paper rots. All barriers will eventually break down, however, and we are satisfied that the combination we chose was the best we could do in our circumstance within our budget.

The summer following its sowing on the sod of our roof, rye grass was harvested as straw mulch, and the area was sown to buckwheat. On a small scale, buckwheat is easy to raise, harvest, and winnow. This area provided us with about the right amount of grain for buckwheat pancakes throughout the year. The well-watered sod on our roof contrasted with the surrounding normally parched soil and therefore became an attractive environment for gophers. Gopher holes abounded. The question arose: do gophers eat bentonite? Our wonder increased when, in time, the smell of rotting flesh emanated from one of the gopher holes. Another question occurred to us: do gophers die from eating bentonite? Ingestion of an expansive clay could wreak havoc on a physiology unaccustomed to it. Had we happened on a solution to the perennial gopher problem yet found folly in the solution to waterproofing an underground structure? Nevertheless, after two rainy seasons (one of which broke all records for 100 years with almost 90 inches of rain), our roof does not leak, and we view with

humor the fantastic claims made by manufacturers for their waterproofing products. The underground living soil laboratory is so rich and alive that the unexpected is inevitable. Still, we anticipate many years of satisfactory shelter from this roof. Reroofing would be a rigorous but not formidable task.

Protected by a French drain, waterproofing on the walls could conceivably last for the life of this building, perhaps hundreds of years. This long term approach to solving the problem of waterproofing is appropriate. No one would ever want to dig out those back walls to rework them!

Again, these waterproofing materials and strategies were selected for their durability, availability, and general appropriateness to the owner-built project. We believe these applications compare favorably with the more complicated manufactured materials so often advertised as suitable for applications underground. Most of the laminated, monolithic membranes require the applicator to have a high level of skill, specialized tools, and are not suited for use by the do-it-yourselfer.

Waterproofing is one more area in which building underground is a gamble. Because this was an owner-built low cost house, the stakes were not unreasonably high. Had we paid five to ten-times what we did for this house, which is what people must pay for commercially-built underground housing, perhaps we would have judged the risks less acceptable for ourselves.

GREENHOUSE DESIGN

An attached solar greenhouse is a most useful, productive, and enjoyable addition to any home and a perfect complement to an underground house. A greenhouse can provide cost-free heat for your house and appropriate space in which to pursue the thrifty hobby of indoor gardening. From cold northeast winters to hot southwest summers, solar greenhouses in their many forms have proved their worth by reconnecting people with the source of their food, energy, and health. The result is to weaken the chains that bind us to imported energy, travel-weary vegetables, and mindless mass entertainment.

To design a greenhouse for our underground home, we used the basic principles for passive solar design. There are many good books in print about solar greenhouses. Among the best are: Solar Greenhouse by

Yanda and Fisher, The Solar Greenhouse Book edited by McCullagh, The Complete Greenhouse Book by Clegg and Watkins, and Our Sun-Heated Greenhouse by Helen and Scott Nearing.

Our final design was tempered by previous experience, the materials available to us, and our climate, which has relatively mild winters. Our last home had a 120 square foot attached solar greenhouse which was meant to be a small, efficient space for heat gathering and plant growing. However, it was such a pleasant space that everyone wanted to be there---children, guests, grownup gardeners, even the cat. We resolved to build this sunspace as large as possible to provide plenty of floor space for many uses.

The greenhouse was built on the south wall of our underground structure, between the kitchen window and the sleeping pod door. The depth was determined by adding the dimension of solid roof necessary for summer shading to the length of two patio door thermopanes (see figure 5.52). This created a semi-private intermediate space between outdoors and the earth-enclosed interior. The result was a greenhouse structure 33 by 15-feet, 450 square feet.

The greenhouse buffered the only exposed wall of the house from the exterior cold and winds. Since several doors and windows opened between the house proper and the long greenhouse, any supplemental heat moved easily into the house by natural convection.

Glazing. Sunlight flowing through glass energized the greenhouse system, promoting photosynthesis and plant growth, providing heat gain and lighting for the house interior, and affording house occupants a view of the outdoors. There are many choices for greenhouse glazing, many types of fiberglass and plastics. We chose glass. We wanted the visual clarity available only with glass, even for the roof. Glass is manufactured from a natural material---sand. It ages very slowly, becoming slightly more brittle, but no less transparent. Plastics and fiberglass degrade rather rapidly under intense summer sun and would need to be recoated or replaced periodically. The fire hazard of styrene monomer (used in fiberglass), acrylic, and polycarbonate plastics is considerable: the acrylic dome "Biosphere", which was the U.S. Pavilion for the 1967 Montreal Exposition, was consumed by fire in 15 minutes, releasing billows of toxic smoke. Finally, we were able to buy inexpensive patio door rejects, which

we made into thermal panels. Glass was the right choice for us.

Summer Cooling. The entire greenhouse roof was glazed except for the bathroom roof which would support the solar water heater, and three feet of roof directly adjacent to the main house south wall. Here, closable vents alternated between areas of conventional solid roofing. These openings allowed excess summer heat to escape, while the section of solid roof blocked the high summer sun from entering the main part of the house. Glazed roof sections were covered with bamboo shades. We intend to experiment with various white wash paints that will reflect the sun's rays. Two sliding doors and an opening window provided ventilation. In summer, several vertical glass panels are replaced by screen, since we have a virtually rainless five months. With these arrangements, this greenhouse was a pleasant place to be during the summer, except for the hottest days. Even then, house interiors stayed cool if they were closed off from the greenhouse.

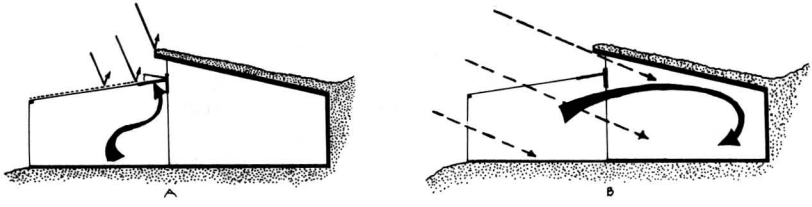


FIGURE 5.46 A---Summer cooling. Solid greenhouse roof section and bamboo shades deflect summer heat gain. Vents and cross ventilation prevent overheating in the greenhouse. Underground interiors keep cool due to earth sheltering.
B---Winter warmth. Low winter sun warms thermal mass. Surplus greenhouse heat is convected to house interior.

Winter Warmth. We designed the greenhouse to maintain adequate warmth for hardy plant life and provide some heat for the house through passive solar gain. The long southern orientation allowed low winter sun full penetration of the entire greenhouse and into the house proper, warming the slate floors and concrete planter beds. This warmth, held in masonry mass,

re-radiated when the sun set and air temperatures dropped. The whole underground portion of the house functioned to warm itself in a similar manner, but the greenhouse experienced much greater swings in temperature. Rather than install movable insulation, which is usually bulky, difficult to store, and often flamable, we decided to accept the heat loss and depend on thermal mass to warm the plants. For extended cold and cloudy periods, we planned to provide the greenhouse with supplemental heat from the masonry wood stove.

Thermal Mass. Masonry planter beds and a masonry floor area were the principal thermal mass in our greenhouse. Although underfloor rock storage beds have been used successfully in many homes, we felt that the warm and moist environment created there might eventually lead to odor and pest problems. In our last solar greenhouse, we had used second-hand 55 gallon drums, painted black and filled with water, as thermal mass. Water is often recommended for this purpose, because it can store three to four-times as much energy per pound as masonry or rock. However, these drums were unsatisfactory: they were ugly, took up too much floor space, and left little room for plants. One drum developed a small leak and made a rusty stain on the concrete floor.

Deep growing beds, besides providing thermal mass, were beneficial to plant growth. Often plants are adequately contained in small pots, but their roots are subject to cold temperatures by their proximity to container walls. The mass of soil in a large bed, however, changes temperature slowly, promoting steady root growth and beneficial reproduction of soil microbes. Masonry beds raised the plants above cool ground level to a warmer one that was more conducive to growth. They also held a great quantity of soil, allowing us to plant small size though deeper-rooted trees and shrubs. This quantity of soil had the thermal storage capacity equivalent to rock. Soil served multiple purposes, not accomplished by water in drums or rock under floors.

Greenhouse Bathroom. We located our bathroom in the greenhouse, creating an interface that benefits both spaces. One wall of the tub/shower was openable windows (polycarbonate for safety) allowing sunlight into the bathroom.

On cloudy winter days and evenings, when the masonry wood stove warmed the house, heat radiated through the back of the stove to the bathroom. By opening the bathroom windows and door, warmth flowed into the greenhouse without causing cool drafts within the house.

Management. The greenhouse is not just a room added onto a house; it is a whole ecology in miniature. A living systems laboratory, it teems with action, from soil microbes, insects, and plants to the people who care for and benefit from the harvest. It is not humanly possible to be totally in control of all greenhouse interactions, but the successful gardener will develope observant eyes and caring hands. The intensity of greenhouse life is restful, not stressful, and its rewards are genuine.

Each greenhouse environment differs in many ways---climate, design, and care. All greenhouses will temper outside weather extremes and protects plants from wind, storms, and frosts. Beyond that, it is up to the greenhouse gardener to maximize potential benefits.

Daily Observation and Record Keeping. A daily record of high and low temperatures both inside and outside will graphically illustrate the thermal characteristics of your greenhouse and help you schedule appropriate planting times. Take a few moments to survey all your plants for surprises such as the first pea blossom or chili pepper nodule, or problems, perhaps an aphid infestation or wilt. Gently shake a few plants to check for white fly. You may enjoy examining plants or insects with a magnifying glass. A chart showing what was planted where and when is invaluable.

Soil. Greenhouse soil is used more intensively than garden soil. Dense and continuous planting and higher temperatures create nearly tropical growing conditions; the humus, or organic matter, in soil may be quickly depleted. Begin with soil rich in organic material, and add sand, compost, and vermiculite. Avoid clay soils. Greenhouse soils must drain well. Do not bring in garden soil in which tomatoes, peppers, eggplants or brassicas (the cabbage family) have recently grown, as these soils may contain diseases and unwanted bacteria. Rich forest topsoil sweetened with dolomite lime may be used. Consider adding some bonemeal or cottonseed meal. Experiment with mulch. It may add to and protect humus in the soil, conserve

water, and create soil warmth. Be aware that it may also hide insects and fungi.

Remove the top two inches of soil from your greenhouse planter and renew the soil with compost or other organic fertilizers before planting each new crop. You may even adjust the soil pH to your plants' preference. In permanent beds like ours, dig deeply and stir the soil well. Experts recommend a complete change of soil every one to five years. Following the above advice should lengthen the useful life of your soil.

There are alternatives to standard soil cultivation. Our favorite is earthworms. The blue variety actually ingests soil, while the common red wiggler requires manure or compost. Their castings make a rich potting soil.

Hydroponics and straw bale culture are soil-less systems for use in greenhouses. Hydroponics is a highly technological system in which plants grow in a sterile medium, such as sand. They are mechanically fed a chemically balanced diet. Because of its complexity, we do not recommend it.

Straw bale culture is used in commercial greenhouse production of tomatoes in Great Britain. Liquid fertilizer is applied to well-soaked bales. The straw composts, generating some nutrients and warmth. The bales are topped with well-finished compost into which tomato seedlings are planted and fed weekly. After harvest, the straw is removed to the outdoor garden where it becomes high quality mulch. The empty greenhouse containers are disinfected with dilute liquid chlorine bleach. This system deserves further investigation for use in attached greenhouses. In design and construction, planter beds could be sized to hold the bales, facilitating removal of finished straw.

Humidity and Watering. Greenhouse plants generally prefer a relative humidity from forty to sixty percent. While humidity in the average home runs between 12 and 20 percent, higher levels are believed beneficial to human health (see The Healthy House by Ken, page 53). On hot dry days, water can be sprinkled on greenhouse floors, providing cooling and increased humidity. Misting helps. In most states, adequate watering of greenhouse plants will increase the moisture content of air exchanged with the house, favorably increasing the humidity of house interiors. In the Maritime West, where outdoor winter humidity levels are nearly 100 percent for days at a time,

additional moisture in the greenhouse may become a problem. One oceanside resident of a small cabin with an attached solar greenhouse complained of bronchial infections and limp newspapers. Use of supplemental wood heat, which has a drying effect, or perhaps a mechanical dehumidifier, might solve this problem.

Excess humidity should be avoided, for it encourages vegetative growth at the expense of fruit and flower production. Certain plant diseases, like damping off, are a scourge in excessively humid environments. Water early in the day, and maintain adequate ventilation.

Ventilation. A tightly closed greenhouse, though the best solar collector, may create a stagnant environment, slowing plant growth and speeding reproduction of plant pests and diseases. Keep air moving whenever possible, either through the house or to the outdoors. Do not overcrowd plants, especially seedlings. Plants need adequate air circulation to provide the necessary carbon dioxide for photosynthesis.

Space Use. Permanent planter beds have advantages, but don't put them everywhere. Open floor area can be put to a variety of uses, depending on seasonal need and family preference. Early spring brings the most demand for greenhouse space. Removable tables, shelves, and hanging racks may then be filled with seedling containers that can be stored as summer arrives and plants are moved into the garden. Larger perennials, for example papayas and citrus trees, thrive in tub-size planters, such as halves of wine barrels. They may be moved about the greenhouse or to the outside, weather permitting.

Pest Control. Plant pests and diseases love the greenhouse environment more than the plants themselves. Insects thrive in a warm, moist environment. Glass excludes the sun's ultraviolet light, encouraging fungal and bacterial growth. Diligent observation and immediate action are the best defense against infestation. Remove diseased plants and bug-pestered leaves. Be aware of introducing problems into the environment on gloves, tools, and new plants. We believe organic control methods are best suited to use in attached greenhouses. If your winters are cold enough, you can freeze out lingering pest problems by leaving the greenhouse open for a week of cold weather.

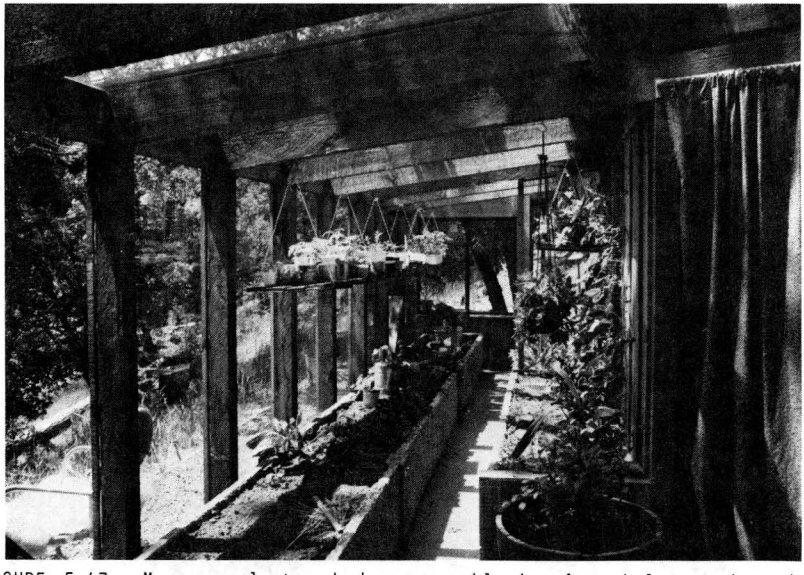


FIGURE 5.47 Masonry planter beds, removable hanging shelves and wooden tubs provided flexibility in this section of the attached greenhouse.

GREENHOUSE CONSTRUCTION

Building the greenhouse was the most joyous part of our house project. Its construction contrasts sharply with that of the underground portion of the house. Forces and loads on the greenhouse structure were light by comparison with those bearing on the house. We shared a light-hearted quality while working on this glass house. Light is the essence of growth and the greenhouse experience.

The footing of the greenhouse was placed on four feet of fill dirt located along the front of the building. Rather than excavate the entire footing down to grade, five holes were dug to a depth of about five feet. Each hole reached a foot below original grade level. A concrete pad was poured into the bottom of each hole. and a concrete column was poured on top of that to the level of the greenhouse "footing." This "footing" is properly called a grade beam. The forms used to pour the columns were cardboard ones used in heavy construction, purchased from a contractor who had left them in the rain. When water damaged, they were worthless to him for they could not be used in

their full 20-foot length. We bought two damaged tubes for $5.00 that were adequate for our small scale application. Bearing weight would be transferred from grade beam to column to footing, providing a solid foundation.

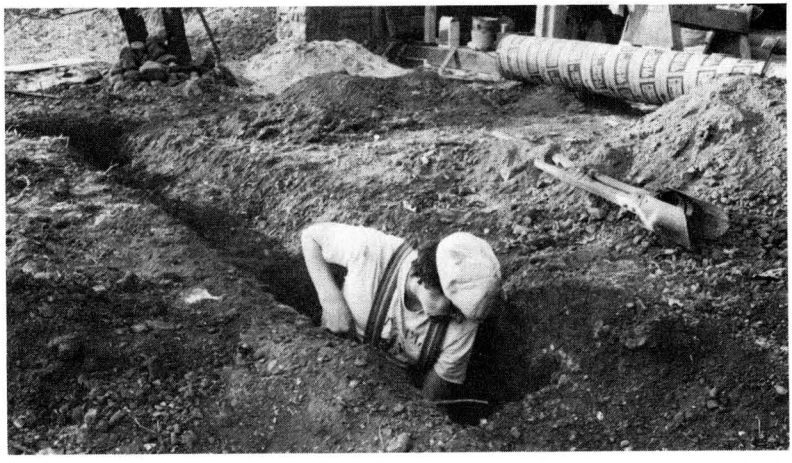


FIGURE 5.48 To provide solid footing for grade beams, holes for the support piers were dug through fill into undisturbed soil.

FIGURE 5.49 Forming for greenhouse grade beams.

The other force that came into play was the outward push of fill dirt as it settled. This force would act to push the grade beam of the front greenhouse wall away from the building. To prevent this, in addition to two side wall grade beams we added two small grade beams which extended from the front wall of the greenhouse to the front wall of the house. We had left two feet of steel rebar sticking out of the south wall footing of the house to which we would tie the steel of the greenhouse footings and grade beams.

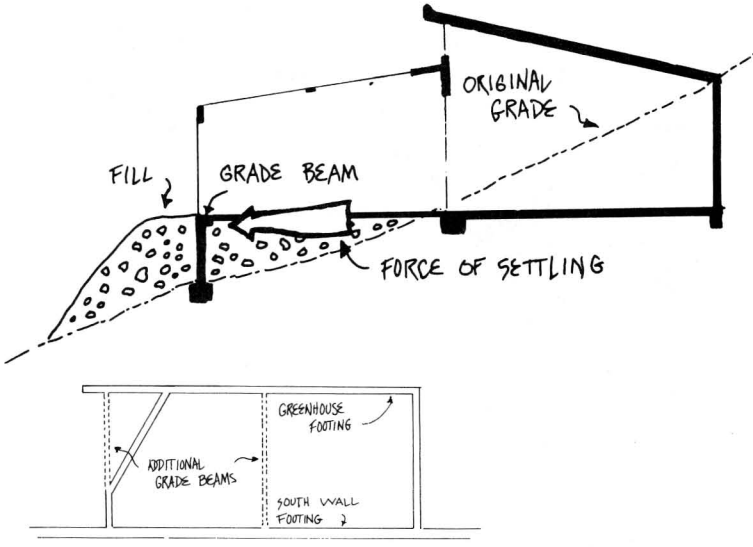


FIGURE 5.50 The greenhouse south footing was securely anchored to house south wall footing by additional grade beams. This prevented movement caused by the settling fill.

On top of the footing, we placed a redwood sill, which had been ripped on the table saw into a water table. From this table, 4 x 4 posts and 4 x 8 rafters were framed in a standard post and beam fashion.

The 4 x 4 posts were spaced on thirty-five-inch centers in order to receive 34 x 76-inch double glazed patio door rejects. In summer, glass in the middle four panels was removed and placed on top of the glass to either side for storage. The open bays were screened until fall. The foam gaskets on both sides of the center panel were the high quality self-sticking type. The glass panels were held in place by compression, sealing out air and water.

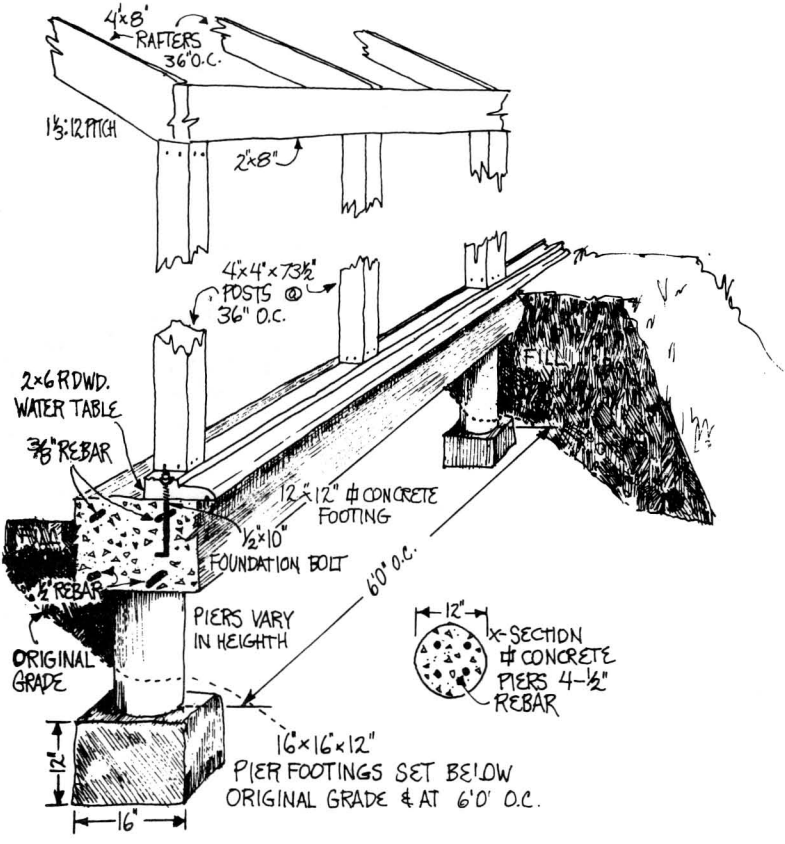
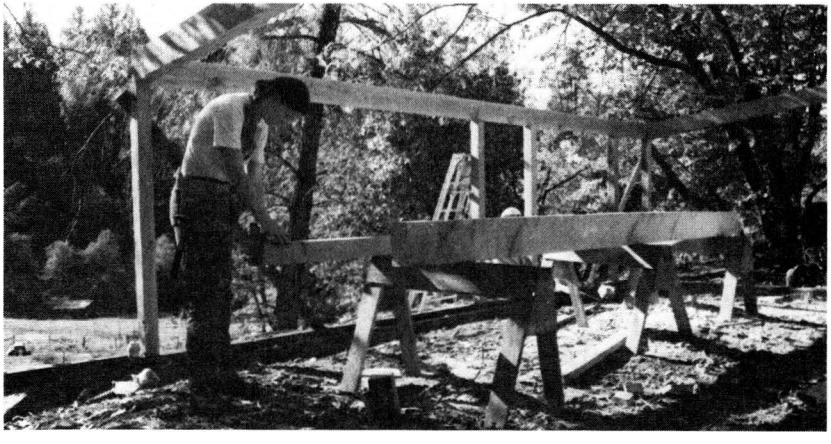


FIGURE 5.51 Greenhouse footing and framing details.



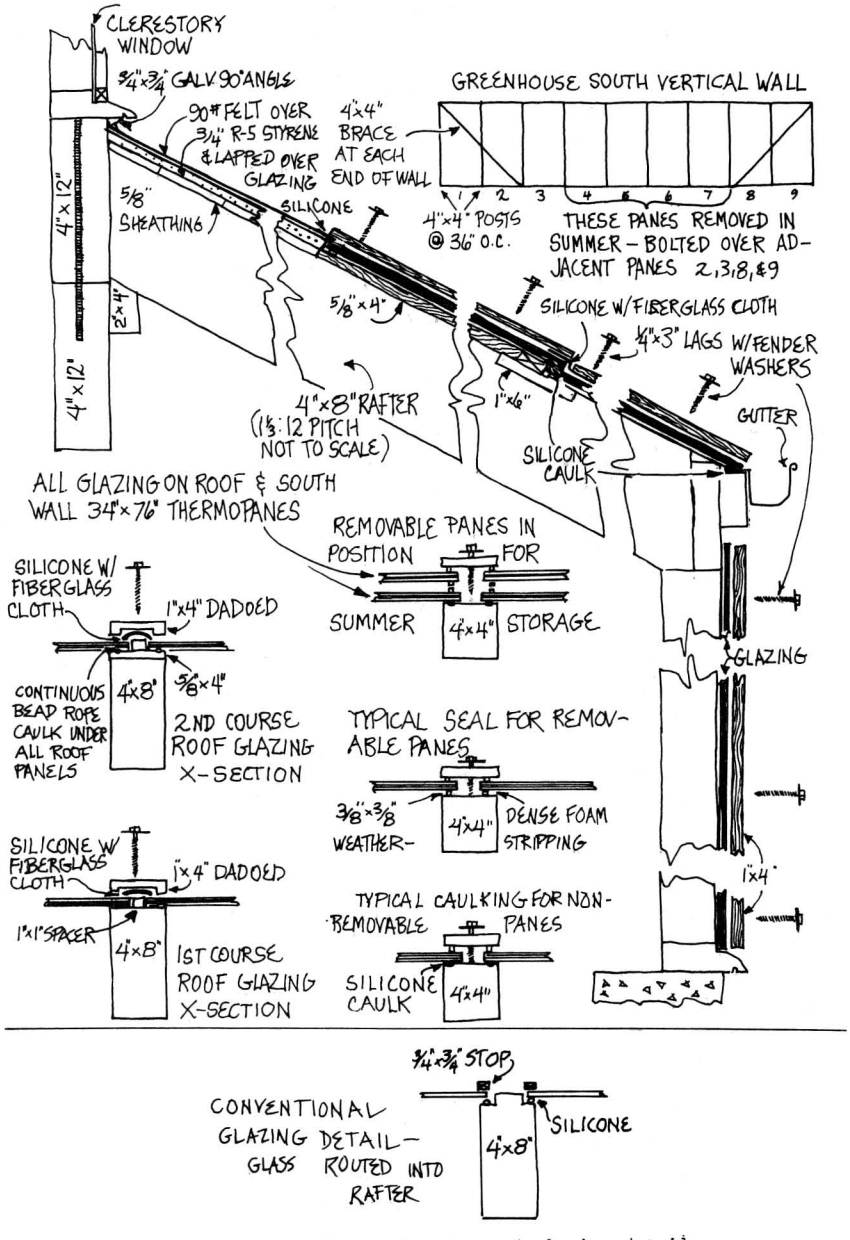


FIGURE 5.52 Greenhouse framing and glazing details.

Rafters were 4 x 8s on 35-inch centers, accomodating the patio door thermopanes. We tried an unusual glazing detail on the roof, one that has worked well. Most greenhouse builders do not recommend glazing an almost flat roof, but we could not resist. This room would serve not only as greenhouse but as living space for sleeping and playing. Since we had purchased a lot of inexpensive, slightly blemished, insulating glass, we could not build a roof cheaper than glass.

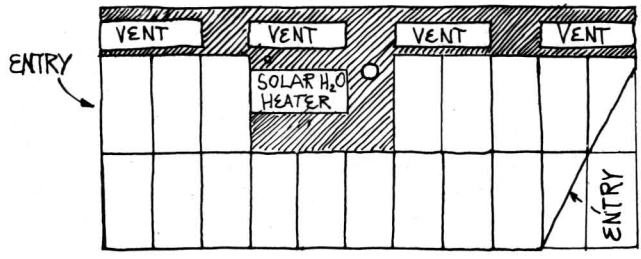
Normally, glass is routed into a rafter (see illustration). We had used this detail before to build at a fairly steep pitch, and still we had trouble with leaks. Caulking becomes brittle and there is no flexibility to allow for the movement that is inevitable in a building. So we decided to put flexible waterproofing membrane above the glazing rather than below it. In our detail, the wooden stop rises slightly above the insulated glass. When glazing tape is applied, it rises slightly up and over the stop. The bolt for the batten screws into this stop. Thus, the bolt penetrates the waterproofing membrane on this ridge. Only in a severe wind would rain ever blow up the ridge and contact the holes in the membrane. After two rainy seasons, the system is without leaks, and there is no sign of degradation in the glazing tape. The tape we used consisted of two inch fiber glass cloth and silicone seal. The fiber glass cloth was designed for use in dry wall taping and had an open weave, allowing the silicone to penetrate easily.

Silicone caulking seems to be the best and most long lasting sealant available at present, but it may have some adverse health effects. Silicone releases acetic acid (respiratory system irritant), methanol (nervous system poison), methylene chloride (known to have caused fatal heart attacks in those with severe heart conditions), and organic peroxides (skin and eye irritants). Silicone should be used with adequate ventilation.

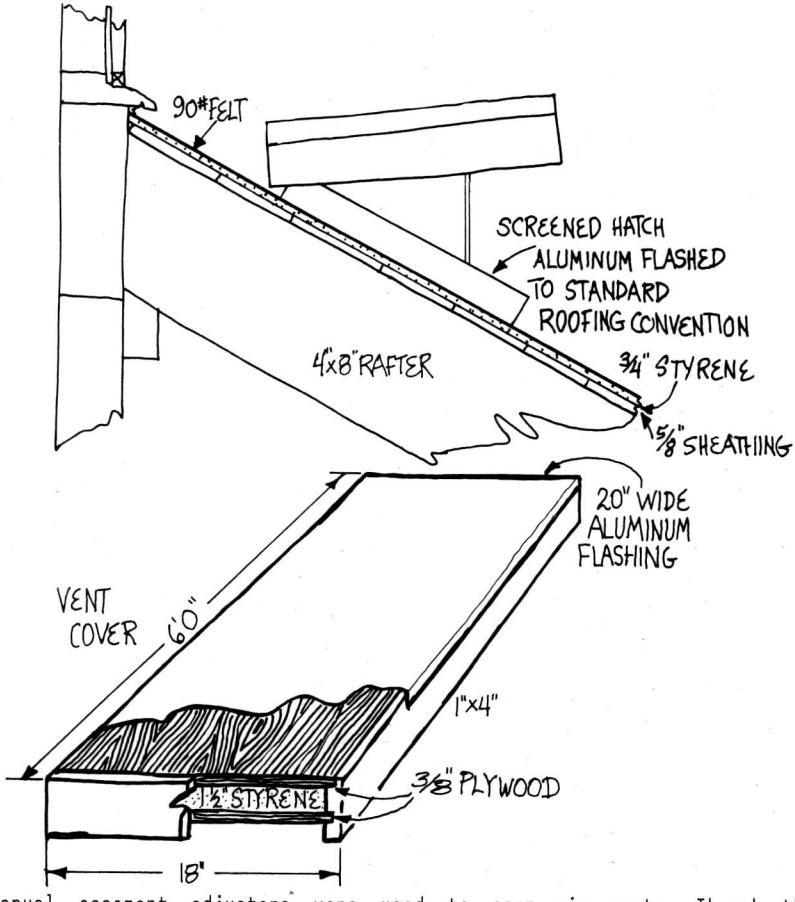
The glazing on the roof spans 12 feet. We overlapped the panels like shingles. This point is probably the most vulnerable to leaks, but we have had none.

The three foot section of roof above the glazed area serves to block summer sun on the south wall of the house proper. It has four large, openable vents. Heated air is allowed to escape at this highest, hottest part of the greenhouse before it reaches the house.

FIGURE 5.53 Greenhouse vent details.



Schematic layout of greenhouse roof. Shaded portion was conventional roof. All air vents, plumbing vents, chimney, and solar water plumbing used inexpensive, standard roof flashing materials and techniques.



Manual casement adjusters were used to open air vents. Though this adjuster was more difficult to operate than the crank type, its solid construction and simple design assured many years of maintenance free use.

Under the floor of the greenhouse, perforated drain lines were installed in trenches. These drain lines were a continuation of the drainage system of the house. After the bath was plumbed, the whole floor was leveled with not less than two inches of pea gravel. The floor was finished above the gravel with concrete, soil cement, and permanent planter beds.

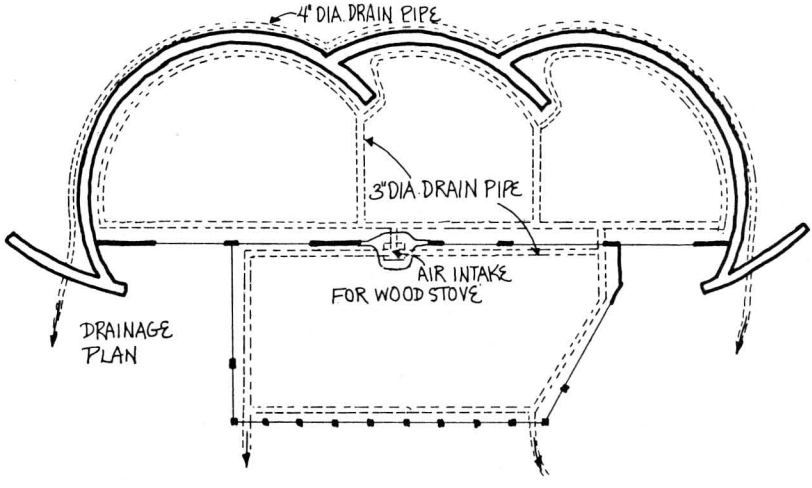


FIGURE 5.54 Drainage plan for house and greenhouse.

These planter beds were constructed of thin walled, tilt up concrete panels. This technique has many advantages. There is a minimum of form materials: about 75 linear feet of 2 x 2 lumber was all that was required. All panels were reinforced with 6 x 6 welded wire mesh. Those that faced south were finished with black oxide cement color, giving the raised bed maximum heat absorption. Those facing the interior of the house were finished by exposing the aggregate in the concrete. Here, the concrete is washed with water several hours after it is poured. Sand and cement readily wash off the surface, leaving a pebbly exposed surface. The mix we used was five parts 3/8-inch aggregate to one part sand. A larger aggregate does not make an attractive surface, nor is it useful in a

concrete panel as thin as this one. At the ends of the beds, the 6 x 6 wire in the panels was bent back and embedded in sand. After the cured panels were positioned, these wires protruded and made it possible to join the ends by pouring small concrete panels in place. In the middle, the panels were joined with 36-inch all-threaded rods.

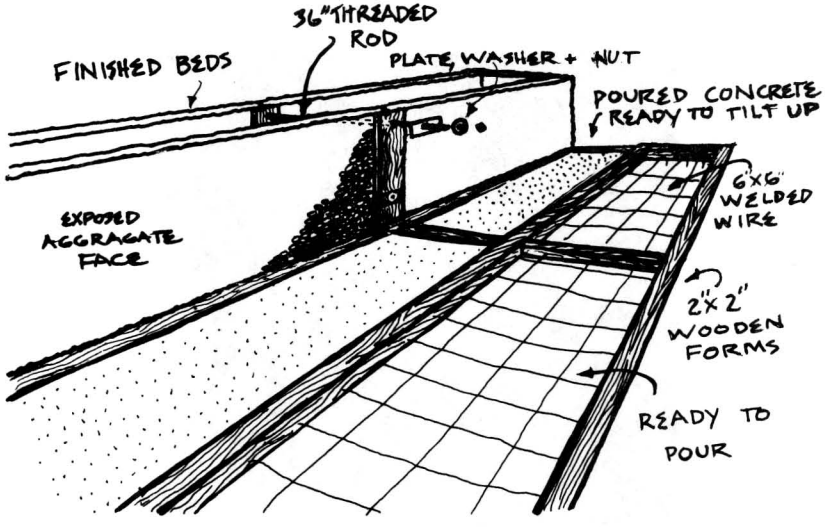


FIGURE 5.55 Concrete planter bed panels, measuring 2-foot by 8-foot by 2-inches-thick, were positioned easily by two people. All-threaded rods held them together at splices. Ends were formed and poured in place, and wood from the forms was left for a pleasing appearance.

FINISHED FLOORS

House floors were covered with four types of low cost finished flooring: recycled slate, recycled oak tiles, pigmented concrete, and soil cement.

Slate. The slate was acquired in a unique way, as are most recycled materials. A seventy-year-old roof had been stripped as its slate shingles softened. The owner had stacked these shingles behind his garage. A friend, who had rented a nearby house and noticed them, mentioned them to us in conversation. Because we had an immediate need for floor surfacing

material, the owner was contacted. Having lost interest in using them, he was delighted to have them carted off. This type of recycling opportunity is not uncommon when you have a community-wide reputation for seeking cast-off materials. People love to see worthwhile materials used, not wasted. Often they will make a special effort to notify you of a prized commodity.

The slate shingles had softened around their edges and nail holes, so each had to be trimmed. A slate nibbler, devised of angle iron, worked like a paper cutter. The slates were washed, trimmed, and graded.

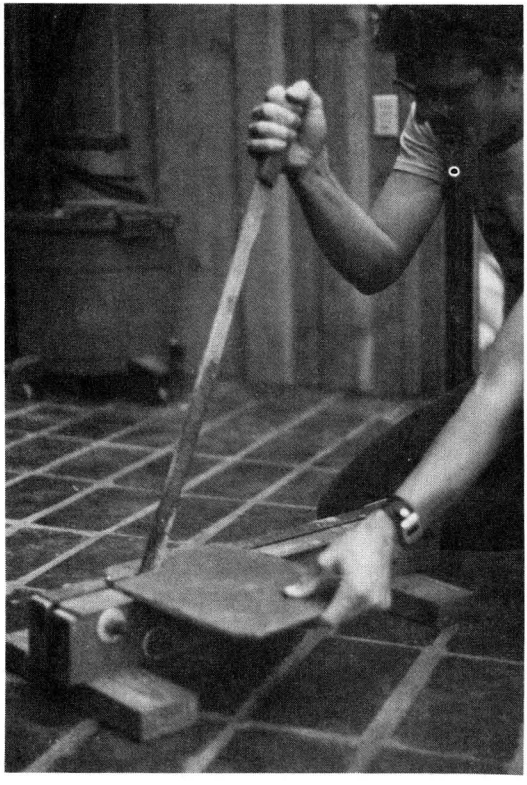


FIGURE 5.56 A homemade cutter recycled roof slates into floor tiles.

To lay slate, a product called Thin Set was used. A cement-based adhesive, it is commonly used to bond ceramic tile to concrete. A pattern was first marked on our concrete floor slab with a chalk line. A 2-foot by 4-foot grid was laid parallel to the south

wall. Thin Set was then applied to these small squares with a notched trowel and the slates were bedded in the mortar, according to this pattern.

Once the Thin Set had dried over night, joints between the slates were grouted. Using our drill mixer (refer to p. 149), 50 percent cement and 50 percent fine grained blasting sand, colored with black cement pigment, were blended in a bucket. This mortar, or grout, was forced into the joints between each shingle, using a hand trowel with a foam rubber base. When mortar dried enough to leave a light film of cement on the slate, excess grout was washed from the joints with sponge and water. The floor needed washing several times to smooth joints and clean the shingles. On a warm day, this work sequence may become a frantic matter when cement-rich grout sets up quickly and is difficult to remove from stone surfaces.

This finished floor was allowed to cure for two weeks before a floor sealer was applied. We wanted to use linseed oil because flax (its source) is environmentally benign, non-toxic to the applicator, and non-toxic as a play surface for children. It proved disappointing, however, when we discovered that linseed oil was not compatible as a sealer for this particular slate. It puddled and was not absorbed even when thinned with mineral spirits. So we used an acrylic floor sealer, which was somewhat toxic to the applicator, environmentally suspect at its origin (the chemical plant), and not fully studied for its possible long term rate of degradation and its breakdown by-products.

Oak. Recycled oak tiles were used for the floor area of the sleeping pod. These tiles had been carelessly removed from a government building. Stacked front to back instead of face to face, adhesive on the under surface of one tile stuck to the face of each tile ahead of it. Rejected by the salvager as too time-consuming to clean up, the tiles were bought cheaply for 10 cents a square foot. For a few miserable days we bent over a wash tub filled with 10 gallons of paint thinner to try to correct someone else's mistake.

Finding a laying adhesive for this solvent-saturated tile was difficult. Using a latex-based multipurpose floor adhesive on a test section showed that the tiles would not adhere to the slab. Thin Set modified with an acrylic binder (often used commercially to bond ceramic tile to plywood) would adhere, but the tiles began to delaminate from over-exposure to the water in Thin Set. Finally, we discussed the problem with a

flooring contractor, an adhesive with a base of mineral spirits (used to lay parquet flooring) was tried. This product was expensive, 20 dollars a gallon to cover 50 square feet. It was also quite toxic to the applicator (containing 1,1,1 trichloroethane). But it did provide a satisfactory bond, and its fumes dissipated before we moved in. The floor, once sealed with boiled linseed oil, was quite attractive at the affordable price of 50 cents for a square foot.

Pigmented Concrete. In the greenhouse, two different floor surfaces were used. Pigmented concrete was used to cover the multipurpose area and the bathroom. During the first stages of troweling as the floor slab was laid, oxide pigments were added. Once the concrete was screeded, oxide was dusted evenly over the entire slab, just as the water began to rise in the concrete. Color was mixed evenly into the surface of the slab by using a wooden hand float and a bull float. As steel troweling created a smooth finish in the slab, the color became more uniform. Also, the color became lighter as it dried.

Soil Cement. In the walkway between the permanent planters and in the multipurpose area at the west end of the greenhouse, soil-cement flooring was used. Before laying this material, we experimented with different binding agents for our local soil. Three test sections were poured, the first using cement and soil in a 1:6 ratio, the second using hydrated lime and soil in a 1:6 ratio, and the third using bitumen and soil with approximately 15 percent bitumen to soil (by dry weight). Cement was found to be the only suitable stabilizer for our red clay soil. Neither the lime nor the bitumen set up in a reasonable period of time (one week), and the shrinkage that resulted in the lime mix was unacceptable. Shrinkage in the mix with bitumen was excessive. These results were specific to our local soil type. For ideas on other possible mixes of stabilized soil see Local Materials by Jeff Kahane.

The soil cement flooring had a number of advantages. Using only a steel trowel and eliminating wood float troweling altogether, we finished the slab smoothly. Finish work was done just after the pour was screeded. The slab's surface was made a bit harder by dusting cement over it before it was troweled. Expansion joints were provided. One 20-foot by 16-inch section of floor was poured without expansion joints and it cracked about every five feet. After the floor

cured, it was sealed with boiled linseed oil and waxed. In tests, acrylic and epoxy floor sealers bonded well, but again, from the perspective of environmental sensitivity, we chose to use linseed oil and wax. The finished surface of the soil-cement floor was warm, soft, and pleasing to bare feet by contrast with the concrete slab. If we had experimented earlier with these materials, more of this floor would have been made of soil cement.

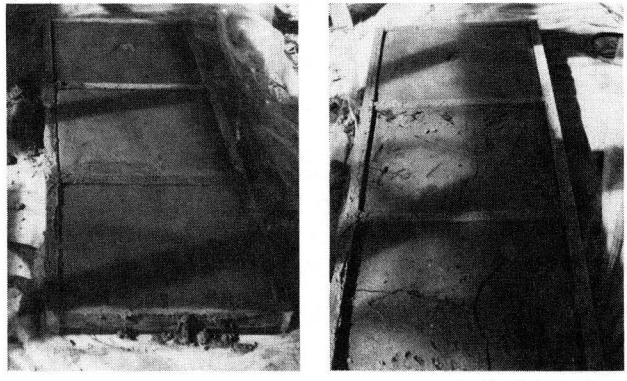


FIGURE 5.57 Soil cement experiments were poured (left) and examined two weeks later (right).

On-site materials. Most importantly, the materials for soil cement flooring were available on-site. This did not have much meaning for us until we scrutinized the source of our building materials. In our current economy, for example, gravel is so cheap and readily available that we lose sight of what is happening at its source. In our area, raw gravel is relentlessly gouged from river basins, forever destroying the pristine nature of the river bed. During mining, grading, and washing operations at the river bank, the quality of downstream water is clouded with particulate pollution which trout find uninhabitable. From the riverside plant, gravel is trucked to local yards and again transported to building sites.

Here, there is a distinct choice to be made, for the implications of a decision to use a lot of gravel are far reaching. Often, even though the choice to build underground is made primarily with environmental considerations in mind, copious amounts of gravel and concrete must necessarily be used. The shallow thinking in which we often indulge should be carefully examined. Should the environmentally aware person

choose to build a massive structure in the light of the necessity to use these materials? Does the underground house truly rate high enough on the Wilderness Scale (see Conclusion, page 256) to warrant use of these materials if, in their procurement, great environmental damage is done elsewhere? As a nation, we tend to examine the source of our material wealth as carelessly as we consider the destination of our garbage. A new and deeper building ethic must be sought, one acknowledging the full circle of events in our lives.

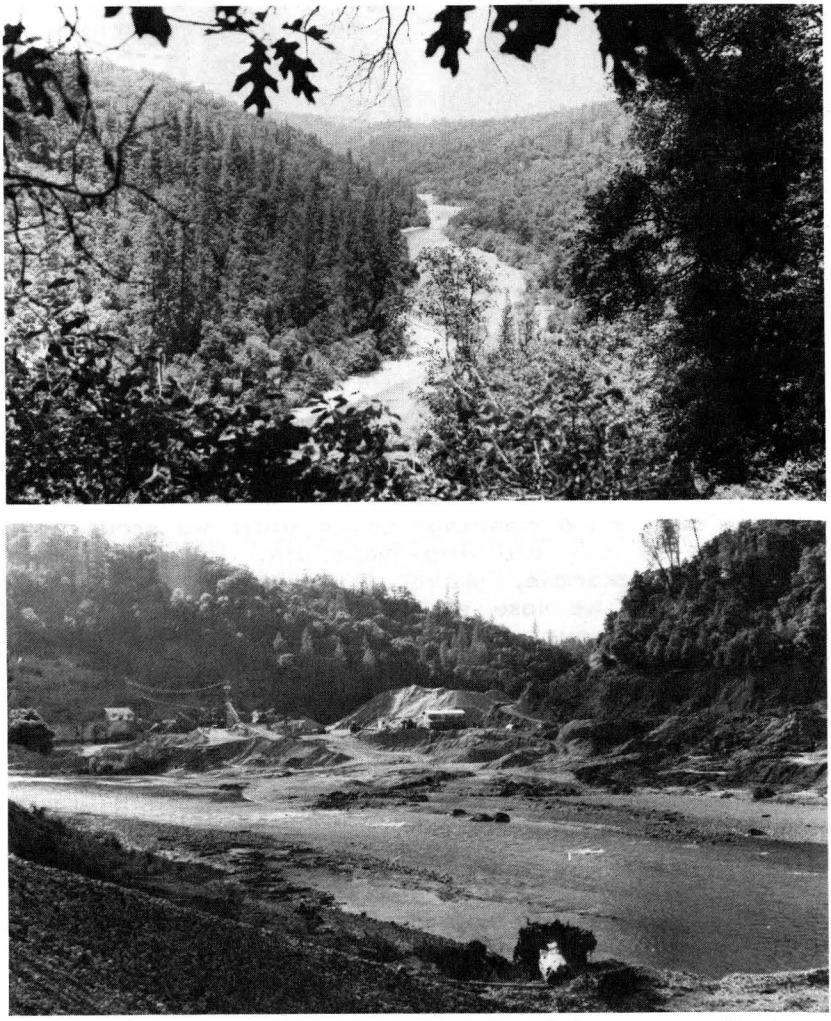


FIGURE 5.58 Pristine river canyon transformed into quarry. We do not often consider the source of the materials we use.

A MASONRY STOVE

Building a masonry stove was another of our experiments in low cost construction. Made of old steel drums and scrap steel, soil cement bricks and ferrocement, this stove was modeled after the double-barrel wood stove, an efficient and time-proven design. Located on the south wall of the house, the barrel comprising the lower portion of the stove was placed so that it would deliver heat to the main, underground living spaces of the house, while the upper barrel was positioned to release its heat into the bathroom and greenhouse areas. A damper was installed in the flue pipe between the two sections of stove, thus controlling the amount of heat delivered by each barrel.

This stove was easily modified to serve other functions as well. A water jacket providing hot water was built into the firebox, a wok was installed in a cooktop surface above the firebox, and a small barrel was placed inside the upper barrel of the stove as a baking oven. Cost of the project did not exceed $300 and required two weeks labor.

Construction Process. We began our stove building by making soil cement bricks with a cinva ram, which compressed our local soil and a cement binder into blocks. The cinva ram is a portable, hand-operated block press manufactured in Bogata, Columbia. It has found wide acceptance in Third World countries, but like other tools involving labor-intensive building techniques, the ram is rarely used in the United States. For a thorough description of gathering and testing soil samples, the correct proportion of cementing agents to soil and how to form these bricks, see The Owner-Built Home by Ken, pages 150-154.

Our bricks were made of soil from our site excavation using a proportion that was 10-parts earth to 1-part portland cement. We screened the gravelly soil through 1/4-inch hardware cloth and mixed the cement and soil together with a hoe. One hundred bricks were made by one worker in each of three 6-hour days. The bricks were damp-cured for a week and dry-cured for another.

Next, we welded drums to make the firebox portion of the stove. Two drums were cut down a third in size and welded together, as illustrated. The lower one served to support the upper barrel, which was the stove's firebox. Its top surface would be ferrocement,

and would be used for cooking. The combined height of these drums was 38 inches.

FIGURE 5.59 Soil left from house excavation was compacted by the cinva ram into bricks for masonry stove construction. Bricks were stacked on the roof of the house to cure.

Wood-heated Hot Water. A water jacket was welded to the back of the firebox drum. Skilled welding and specialized equipment are required to produce water tight seams, so our tank was fabricated at a local welding shop. The water jacket was built of 1/4-inch plate steel for the area that would be in contact with flame. Three-sixteenths plate steel was used for the remainder of this tank, and a threaded bung was placed at the top and bottom. Our outlay for the water jacket was $125, more than a third of the cost of the masonry stove: $50 in materials and $75 for labor. (Top prices are paid for steel purchased through welding shops.)

An electric hot water heater was positioned above and to one side of the wood stove. When the stove was in use, this water heater would be turned off, serving only as a holding tank for wood-heated water circulating to it from the masonry stove by means of natural thermosyphon. Water heated in the jacket of the wood stove would rise to the top of the hot water heater tank. Cooler water from the bottom of this tank would replace water heated in the water jacket.

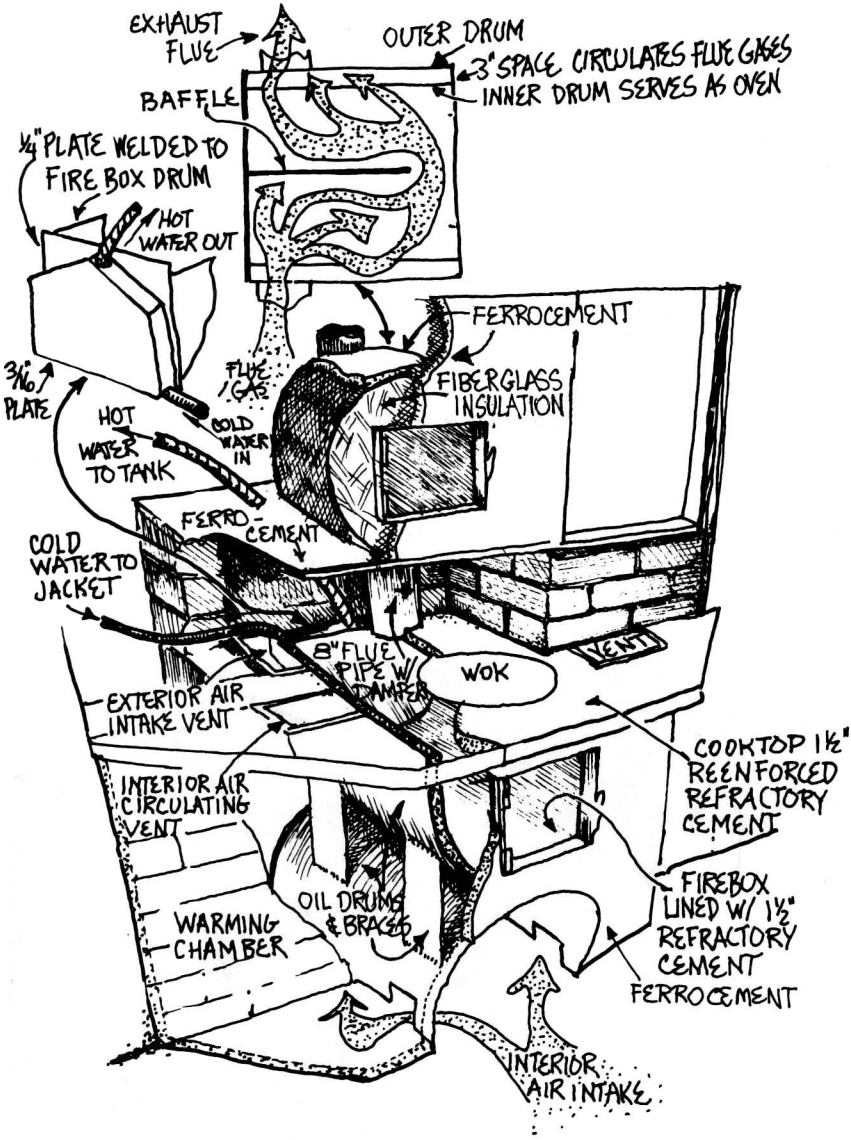


FIGURE 5.60 Masonry stove details.

Brick Chambers. Once welded, the unit was brought into the house, positioned, and its location marked on the floor. The barrels were then removed so that bricks could be laid up without hindrance.

Four chambers were built into the surrounding masonry. Each receives cool air from the floor through inlets at the bottom of each chamber. Air flowing through them heats, rises, and exits from outlets at the top of these cavities. Thus only moderate radiant heat is retained in the masonry for more gradual release to the living area at a later time. Convecting some of the stove's heat prevents build-up of high temperatures on the stove's exterior surface. In a small house, it is important to use the limited space efficiently. With this stove design, a person may sit close without being overwhelmed by radiant heat issuing from the stove's surface, and children need not be fenced away from the stove---as they must from many steel surfaced, wood-burning stoves. Only the small fuel-loading door of our stove becomes hot enough to cause burns. The door has a glass panel of heat-tolerant borosilicate that allows the fire to be seen. This clearly indicates to even small children the presence of heat and danger.

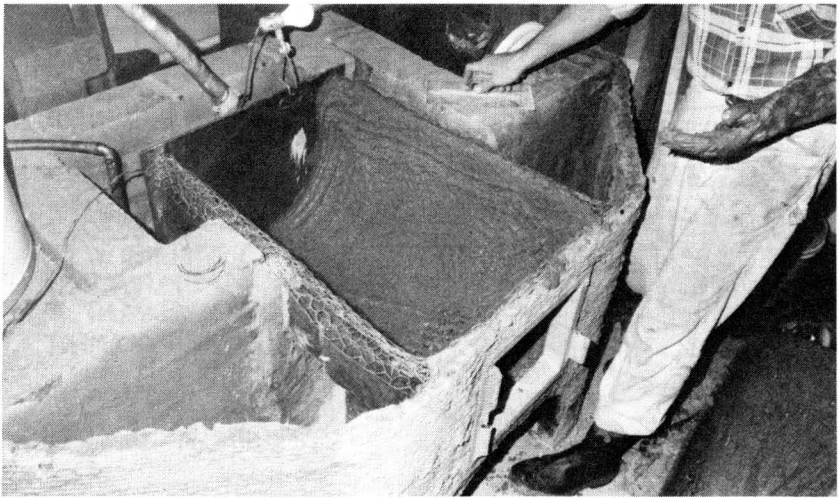


FIGURE 5.61 Masonry walls of brick and ferrocement shaped chambers around the barrel firebox. Interior of the firebox was lined with refractory ferrocement except hot water jacket, which formed the back of the barrel.

Once soil cement blocks were laid in place, they were surface bonded (a fiber glass reinforced plaster). The strength provided by this coating was not really necessary, for a straight, earth block wall may be safely built to a height five-times the breadth of the block used. In this case, our stove slightly exceeded that rule of thumb, but two corners in the design stabilized it. Fiberglass reinforced surface bond plaster was used as an experiment in this instance to see if the earth brick and the bonding plaster were compatible. They did adhere well to one another, and form a composite material that deserves more attention for low cost earth wall construction.

When the stove's earth wall was completed, the welded barrels were positioned and mortared in place. Chamber dividers between the soil block wall and the barrels were completed and gaps were sealed with plaster and reinforced chicken wire as needed.

Ferrocement Work. The front wall of the stove that faced the living area was made of ferrocement. Quarter-inch pencil steel formed the stove's curved shape. The home-welded firebox door was plumbed and braced into position. Rods of pencil steel, extending six inches beyond the door, were welded to all four sides of the frame and fastened the door assembly to the framework of the ferrocement. Five layers of chicken wire mesh were laid against the curved pencil steel form and were fastened with tie wire. A mortar, consisting of 2-parts sand to 1-part portland cement, was embedded in the mesh. This was "scratch-coated" using a tool called a "scratcher." This roughening process leaves a surface that more readily accepts a finish coat of plaster.

The inside of our stove's firebox was plastered as well. Four layers of chicken wire were laid inside the barrel along its sides and around the framework of the loading door. Plaster was made of 2-parts silica sand and 1-part refractory cement. Refractory cement withstands high temperatures and is used wherever masonry is to be directly exposed to the intense heat of fire. It is not commonly available at building material outlets, but may be purchased from specialized masonry product dealers or directly from the manufacturer.*

*One manufacturer of refractory cement is Universal Atlas Cement, Division of United States Steel, Pittsburgh, PA

Some of the chicken wire was left exposed above the top edge of the barrel in order to connect with the masonry slab of the cooktop. While the refractory cement firebox lining cured for a day's time, a plywood form was built inside this barrel in preparation for pouring the cooktop slab. This plywood form would burn out with the stove's first firing. Holes were cut in it for both the chimney and the cooking wok.

Chimney and Cooktop. A 16-inch length of 8-inch well casing made of thick-walled steel was purchased from a scrap steel yard to serve as the stove's chimney. This section of flue gets quite hot, and a thin-walled metal stove pipe would have burned out in a few years. An 8-inch-diameter damper was installed in this section of chimney pipe to control the distribution of heat to various parts of the house.

A flue hole, 7 inches in diameter, was cut in the plywood form. This provided a 1/2-inch rim of support for the 8-inch chimney pipe, which would be set in wet ferrocement when the cooktop was poured. To form this lip, a small, circular collar of sheet metal was nailed to this opening in the plywood; it would hold wet concrete in place during the pour and would fall into the firebox when the plywood form burned away.

The opening for the wok was cut so that the top edge of the pot would be flush with the top surface of the cooktop slab. The wok was placed in this hole, and was easily knocked loose from the dried concrete for removal and cleaning.

Sheet metal was used as a form for the sides of the firebox, where the cooktop slab overlapped the air chambers beneath. It was tie-wired underneath to the pencil steel grid. Holes were cut for the duct registers carrying heated air from the stove's air chambers to the household. The purpose of the closable registers was to give added flexibility to the amount of heat delivered by the wood stove. If more heat were desired, the registers could be opened. When closed, heated air would remain in the chamber, charging the masonry of the stove with heat that may be re-adiated more slowly to the living area.

When the plywood form was in position, 1/4-inch reinforcing pencil steel was tied on a grid 4 inches by 4 inches. Four layers of chicken wire were laid over this grid. Refractory cement and silica sand were mixed into a mortar that was poured over the gridwork.

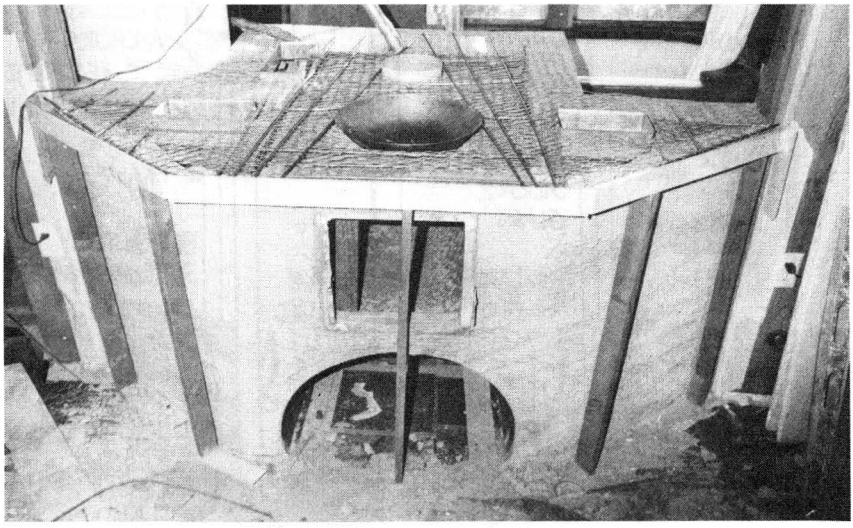


FIGURE 5.62 Form work for cooktop slab.

Three additional courses of brick were laid on top of the cooktop slab. A plywood form was placed over the top course, and a hole was cut in it for the chimney pipe. Pencil steel was tie-wired in a 4-inch by 4-inch grid over the form, and a 1-1/2-inch-thick slab was poured to support the oven barrel. Refractory cement need not be used here, only where concrete will be in direct contact with flame.

Oven Barrel. The top barrel heat exchanger served several functions: a heater for the bathroom and greenhouse, a baking oven with access from the living area, and an auxiliary heater for the living space. To modify the upper barrel for use as a baking oven, a second, smaller barrel was placed inside the outer 55-gallon drum. There were several inches of clearance between the two barrels to allow circulation of hot flue gases that heat the oven of this stove to baking temperature.

A door framework was welded from the steel of an old bed frame. This, in turn, was welded to an oven face plate made from a scrap piece of 1/8-inch plate steel. The inner oven barrel was then welded to this face plate, followed by the welding of the outer barrel to the face plate in concentric circles.

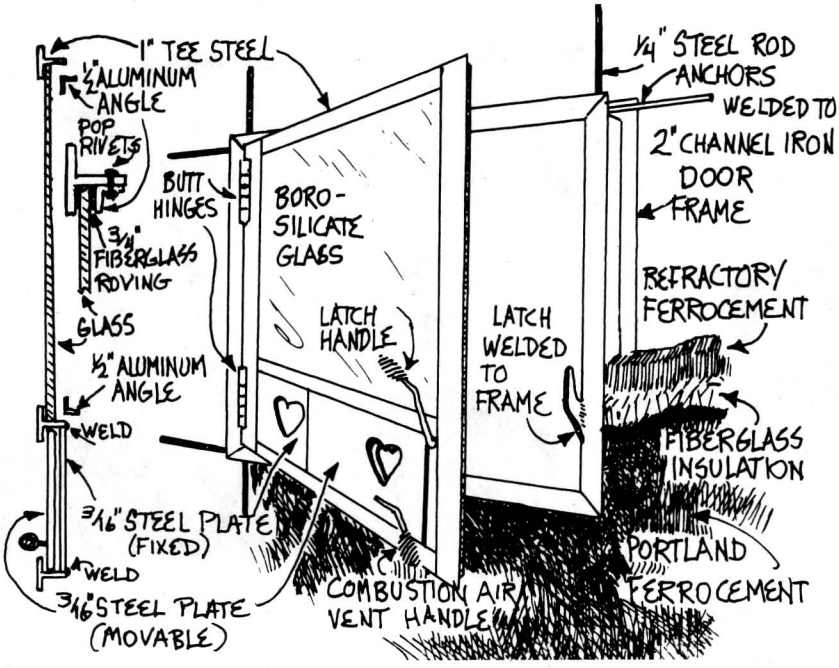


FIGURE 5.63 Details of masonry stove door.

The inner barrel that formed the oven chamber was made from an old, galvanized water pressure tank. (This material was more easily cut by a metal cutting abrasive blade in a circular saw than by an acetylene cutting torch. In either case, the fumes created are laden with cadmium and are toxic, requiring an appropriate respirator.) A simple frame was spot welded inside the oven chamber to carry an oven rack.

Between the inner and outer barrels, baffles were installed to circulate hot flue gases around the oven. This strategy helped heat the oven more evenly and distributed more of the heat of flue gases through the masonry mass to living areas of the house. By leaving the oven door open, heat may be delivered from the upper barrel to living areas of the house when immediate, additional warmth is required.

The 55-gallon drum used for the outermost oven barrel was the type that had a removable lid fastened down with a steel hoop, tightened by means of a bolt. This allowed us to remove the whole back of the barrel, exposing the inner barrel and the flue gas

chamber for cleanout of any creosote build-up.

Before the oven barrel assembly was positioned on its masonry slab, previously spot-welded seams between the barrel ends and the oven face plate were sealed by setting the assembly on the floor, oven door down, and pouring a 1 1/2-inch seal of ferrocement (using refractory cement) into the flue gas cavity. This "gasket," shaped like a doughnut, eliminated any chance of flue gases leaking from these seams.

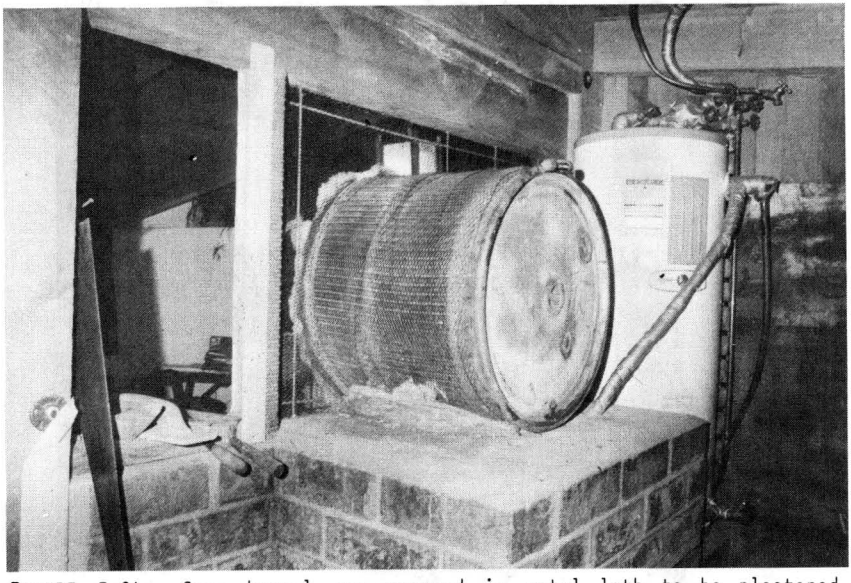


FIGURE 5.64 Oven barrel was wrapped in metal lath to be plastered. Insulated pipe connected hot water jacket to electric water heater.

Finish Plaster. The completed oven barrel was then hoisted into place, its door flush with the south wall of the house. A 1-foot by 1-foot grid of 1/4-inch pencil steel, with expanded metal lath wired to both sides, was then erected on either side of the oven door, creating a partition wall between the bathroom and living areas. Expanded metal lath was also wrapped around the upper barrel, which then received a coat of plaster. This would reduce the immediate, intense heat radiation from this barrel, provide more mass for bathroom heat storage, extend the life of the unit, and improve its appearance. A finish coat of plaster was applied over all rough-plastered surfaces.

The plaster mix was white Monterey sand, white cement, and hydrated lime in a proportion of 6-2-1. This finish plaster was white in color, eliminating the need for masonry paint. Soil cement bricks, which were left exposed in the bathroom, were coated with a slurry of white cement, hydrated lime and water.

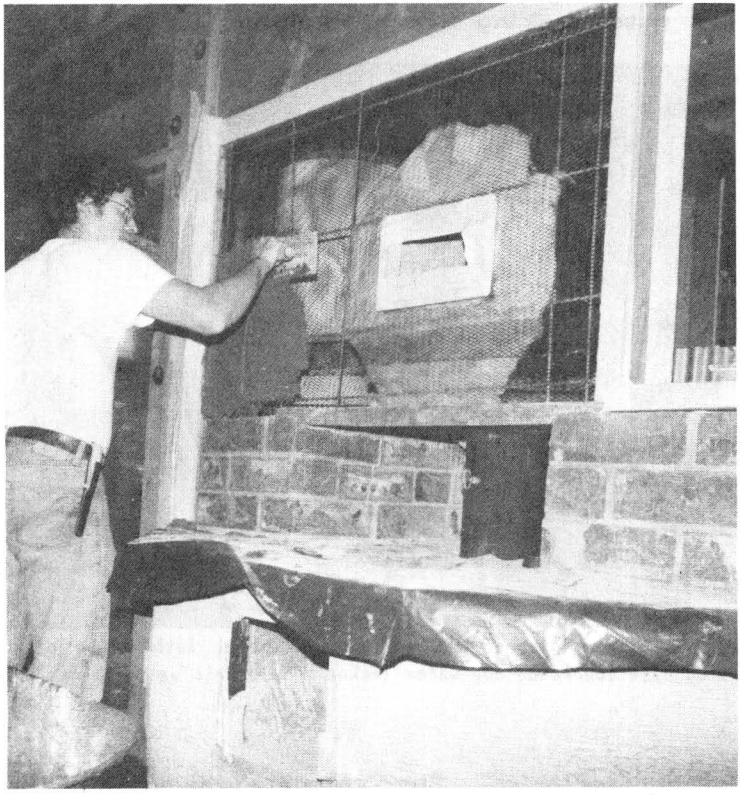


FIGURE 5.65 Metal lath was attached to both sides of a 3/8-inch rebar grid (1-foot x 1-foot) and plastered to form wall between living area and bathroom.

These finishing techniques were selected to eliminate using chemical-based paints. We were living in the house as we built this stove, and we did not care to live with the odors of drying paint. Because Jane was eight months pregnant at the time, we were especially cautious about preventing exposure to the chemical residues and outgasing inevitable with the

use of commercial paints. Also, the performance of chemical paints under conditions of heat is uncertain.

The masonry stove was allowed to cure for 2-1/2 weeks before the fire was built in it. Ideally, more curing time should have been permitted, but with home birth imminent the stove had to be pressed into service.

Variations and modifications for this type of stove seem endless. Designed to be flexible, it served many functions while directing heat to the living and greenhouse areas of the house. Its masonry mass provided heat storage, fire protection, child safety, and a more healthy exchange of heat. It had both cooking and baking facilities and produced domestic hot water as well.

Construction of the stove encouraged the use of local owner-building skills. Materials were either site-generated or purchased locally, except for the refractory cement. Our stove wastes less space than a purchased wood stove, for masonry walls of the stove's chambers buffer the overwhelming radiant heat produced by the average wood stove, making the floor space near the stove usable.

Aesthetically, this stove is pleasing. An added bonus is that we don't have to live with an advertisement for the manufacturer emblazened on its doors. Instead, we are free to watch the fire's glow through a heat resistant borosilicate glass panel in the door. We have enjoyed (and cursed) many different wood stoves over the years, yet none has been as satisfactory as this one.

There was no facet of this building project that required a high level of skill, except for the water jacket which we hired done by a professional welder. The heavy soil cement bricks were not necessary. Thin ferrocement would serve as well, reducing load requirements on the footing. Ferrocement skills are easily learned. This material can be formed to make any shape, curvilinear or rectilinear. There is no aspect of our stove that necessitates "heavy" construction techniques. Here is an opportunity for women, in particular, to break into masonry work, for there is no male dominated tradition or guild requiring extended apprenticeship. Few people are building efficient, curvilinear, custom designed stoves of "light weight" materials.

Problems. Our stove does have some unsatisfactory elements which could be avoided. The soil cement

brick wall has developed some hairline cracks, whereas the ferrocement work remains free of cracks. Soil cement brick may not be suitable where it will be exposed to thermal stress. This is difficult to verify, as site-made bricks differ considerably from one area to another.

One crack has developed on the front wall of the stove, a foot above the cooktop slab. This crack is located at the point where the wall material changed from plastered soil cement brick to ferrocement. The characteristics of thermal expansion for these two materials are obviously different. In retrospect, it was foolish not to expect such a crack, given the change in method of constuction at this point. The change from soil cement to ferrocment should have been made at intersection with the cooktop slab.

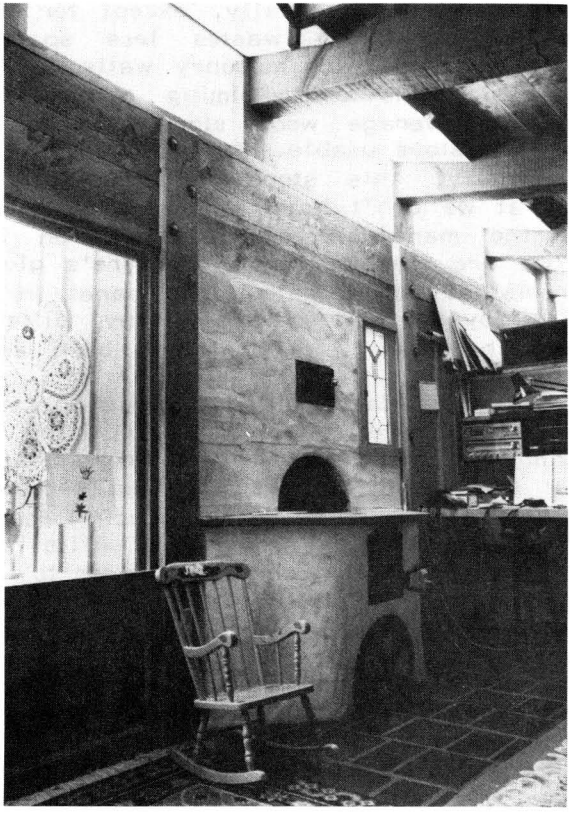


FIGURE 5.66 The attractive, multi-purpose stove tempered its heat so that floor space immediately adjacent to it was usable.

The water tank was enclosed in the soil cement bricks. Though built to last a long time, it should have had better accessibility. A movable panel or access door would have assured easy repair of this unit.

The ferrocement cooktop slab has developed some fine hairline cracks running radially out from the sunken wok. We don't expect any major degeneration of this slab, but we are watchful. Perhaps the wok should be eliminated to create a more unified slab. The part of the cooktop slab in direct contact with flame could be built of 1/4-inch plate steel. A flat steel top would provide a more flexible surface for traditional Western cooking styles.

During the first two weeks of operation, our stove gave off a foul, acrid odor. The source was difficult to locate, but finally determined to be the melting of mineral deposits left on the inside of the small drum used for the baking oven. This barrel was recycled from its former use as a galvanized water pressure tank. On inner walls of the drum, deposits left by the mineral rich water of the Sierras had melted into odd-looking blobs of solder-like material. In a few weeks' time, the odors dissipated, although we refrained from using the oven for baking until all traces of mineral activity had disappeared.

Homemade masonry stoves deserve more interest and attention. They have long years of traditional popularity in Scandanavia and Russia. Efficient fuel users, they stabilize comfortable interior temperatures. A stove of this type could be located on the south wall and used as a Trombe wall. More information and options can be found in the book Ken Kern's Masonry Stoves.

WASTE SYSTEM

A septic tank, leach field, and a flush toilet were chosen as the sewage system for our home because our site was provided with abundant water and the soil had good percolation. The low cost septic tank was owner-built using the same slip form method used to make the curvilinear walls of the house.

There are many viable alternative systems of waste disposal. We are personally familiar with a number of these systems, having built both the Kern and the Van der Ryn styles of composting privies and

having lived on homesteads that were served by outhouses, cesspools, and an Ecolet (a fiberglass aerobic composting toilet). We are also familiar with the Clivus Multrum and its small version the Toathrone, and have built a ferrocement composting toilet based on the Toathrone design. The flush toilet, symbolic of water-wastefulness, has become repugnant to many people devoted to appropriate technology. We feel, however, that a low flush toilet on an owner-built septic system can be well designed for any site where there is ample water and adequate soil percolation. The total cost for our entire system, including toilet fixture, was under $1000, well below the price for many alternative aerobic composting systems. With these dry systems, you still have to construct a small septic tank and leach lines to handle the greywater from the rest of the house. For further information on alternative systems, see The Toilet Papers by Sim Van der Ryn and Septic Tank Practices by Peter Warshall.

Design. To design our system, we estimated water comsumption for our house. All fixtures in the house have flow reducers, and the toilet requires 2-1/2 gallons per flush instead of the usual 5 gallon flush. In good weather, urine is collected outside in a separate container and diluted 10 to 1 for direct use as a fertilizer for raspberries. This further reduces water comsumption. (Annually, one adult's urine yeilds high nitrogen fertilizer valued at about $40.) The container is a 5 gallon bucket placed in a wooden box that has an openable lid. A stainless steel salad bowl is fitted with a 3/4-inch P-trap that flushes with a half cup of water. This is placed over the top of the bucket to elimiate odor. The cost of such a urine receptacle is recovered in about two months' time in fertilizer value.

For a system with such low water consumption, a 750 gallon septic tank was adequate. The length of the leach field was based on the rate of soil percolation and the amount of household water used. Septic systems must be designed for the requirements of both house and site. Septic Tank Practices offers an intelligent and understandable approach to septic system design. A multi-chambered septic tank is preferable. Rather than build a single heavy tank with a baffle, we decided to built two connecting lightweight tanks using thin-wall slip form construction. One advantage was the smaller size and lighter weight of lids for these tanks, as discussed later in the construction

sequence.

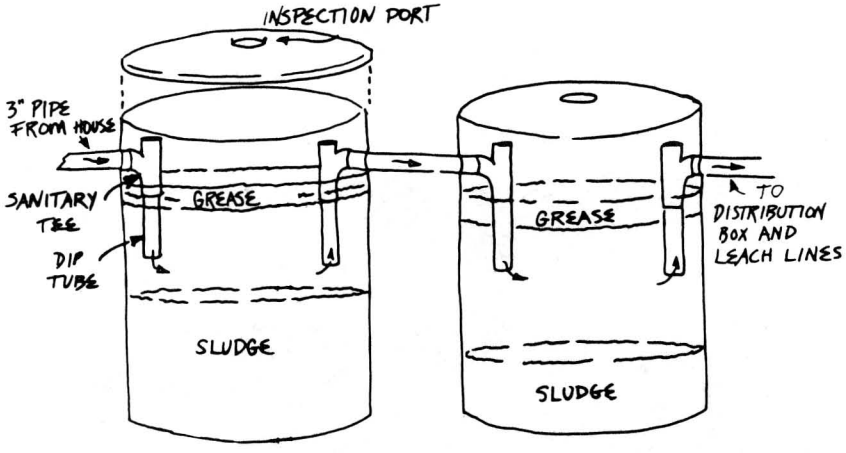


FIGURE 5.67 Details of two tank septic system.

Construction. We chose to rent and operate a large backhoe to excavate for the septic tank and leach lines. While renting this equipment is less expensive by the hour, it is neither cost effective nor safe if you don't know how to operate heavy machinery efficiently.

The bottom of the septic tank hole was leveled and compacted to assure its solid foundation, and a pipe was driven into the center. A 3-inch-thick steel reinforced slab was poured for the base of each tank.

A slip form with a 2-foot radius was built of sheet metal, and walls were formed in the same way as those of the house. These walls were only single thickness, not double wall. The form we built was short in length and slipped forward quite easily.

To unify walls with the tank's floor and thus create a strong water-tight monolithic structure, the inner surface, floor, and the outside of these slip form walls were all coated with a surface-bonding plaster. This coating of rich cement-based plaster was reinforced with 1/2-inch fibers of chopped glass. The mixed plaster was best used with a consistency like that of sheet rock topping compound, and was easily applied to these curving surfaces with an 8-inch sheet rock trowel. A plasterer's trowel is generally used to

apply this bonding material to flat surfaces, such as walls constructed of dry stacked concrete block.

After the surface bonding cured, the sanitary plumbing tees and dip tubes were glued onto the pipes, which had been embedded in the walls of the tanks during slip forming. The inside of each tank was then coated with tar. Before backfilling, the tanks were tested for leaks.

FIGURE 5.68 Low cost septic tanks were built in place using a small slip form. Note on left the distribution boxes for the leach lines.

FIGURE 5.69 Fiberglass reinforced plaster (surface bonding) unified and waterproofed the tanks.

Tank Lids. The covers to the tanks were built of 2-inch thick ferrocement. They were light enough to be handled by two strong people, simplifying access to the tanks when they must be cleaned. The construction sequence of the lids was as follows:

A steel stake was driven into flat ground. With the stake as center pole, the slip form was used to build a temporary circular form. The outside channel of the slip form was removed from the radius arm and the inside half slipped to the outer position. As the form pivoted around the center stake, low quality soil cement was packed against the outside. This created a circular form for the tank lid that was 4 inches in diameter larger than the tanks themselves. Next, the center stake and slip form were removed. Dirt was mounded 4-inches high in the center of the circle, sloping to the perimeter. The lid would be dome-shaped to increase its strength. Two layers of wire, 6 x 6 welded wire mesh and 2 x 2 garden fencing, were laid over the dirt form, and it was filled with 2 inches of concrete, using a grout that contained 3/8 minus aggregate. The wire was adjusted to lie in the middle of the wet concrete as it was poured. This procedure maximized the composite strength of this material.

These lids have enough strength to support six inches of soil and normal loading. They were not designed to be driven over, so landscaping will be used to create a barrier around the tanks to shield them from farm machinery.

A septic tank should be checked every few years. We will maintain and clean our system by removing and hot composting the scum and sludge. This must also be done to the end product of dry composting toilets. The increased difficulty of handling the wet material from a septic tank is offset by the fact that it only has to be done once every five years or longer.

LANDSCAPING

Landscaping, the final blending of the building with the earth, is especially important to underground housing. During excavation there is much disruption of the living environment, but when surrounded by dirt, the finished house creates a unique microclimate in which plants may again flourish.

First Plantings. As soon as our house pad was completed, we built steps on the steep southern slope

of our site. At appropriate intervals we placed cants as retainers and raked gravelly soil into place to form flat treads. This hillside was planted to prevent erosion and begin the long process of making topsoil. Buckwheat, clover, and rye grasses were sown. We fertilized and watered them frequently, since our rocky soil held water poorly. Soon the hillside bloomed, albeit with rather spindly plants, and it reseeded itself with a crop of new growth that lasted into winter. This type of cover crop not only holds soil with its roots but also provides organic matter that enriches the earth. During construction, we distributed over these barren slopes any organic material generated by the building process, such as sawdust and the straw used to cover the slab during the curing process.

Edible and Useful Plants. Frank Lloyd Wright said, "Physicians can bury their mistakes; architects can only advise their clients to plant vines." The well-advised owner-builder today would bury the house and plant productive vines. We wanted our landscaping to perform many functions: to increase energy efficiency, to provide food or other usable products, and to soften the visual impact of the house. We planted many vines: grapes, kiwis, and hops, as living trellises whose leaves would shade the house in summer but disappear in winter to allow penetration of the sun. On the southern slope in front of the house, we placed genetic dwarf fruit trees that were bred to remain short in stature (under 8 feet); they would never grow tall enough to block our view, yet would thrive in the special conditions found there. Though the cultivation of plantings there is difficult, a steep slope provides good air drainage and prevents cold from piling up around plants to create frost. The greenhouse and massive retaining walls radiate heat to these plants all winter. Thus, we grow kiwis, peaches, and nectarines on this slope, even though these fruits are usually considered too sensitive to the late frosts of our mountain area. When possible, maximize the ground area near the house that can be used for planting.

The Roof. Rye grass, clover, buckwheat, and wild flowers were selected for our roof covering. These provided a green barrier against fire and a delectable snack for local deer. When we improve the fencing about our place we may attempt to grow strawberries on our roof using a heavy mulch, no-cultivation sys-

tem. Any digging would endanger the waterproofing membrane of the roof and should be avoided. In the future, we plan to grow squash and melons on the slope behind the house, and to train their vines to run over the roof. This would provide another canopy of shade during summer months.

FIGURE 5.70 Maturing at 6 feet, the genetic dwarf peach tree shown will never grow tall enough to block the view from house interior.

Native Plantings. Much of our cultivated vegetation requires irrigation. Planting and protecting native species well adapted to this locale saves us their watering and pampering, and often provides unique benefits. Two large digger pines in front of our house produce lacy, open shade and delicious pine nuts. We decided to keep them, although we had thought they would block too much sun. Be conservative when removing native trees and shrubs near your house. They take a long time to grow and may be difficult to replace with other suitable vegetation.

Like most new home owners, we have endless plans for improving our grounds. Builders of underground houses must be responsible for smoothing over the scars of excavation, and they have the advantage of being experienced in moving dirt around. We plan to use our left-over backfill dirt to form various

terraces and an outdoor patio. As our plants mature to provide productive crops and to protect our house rather than aggrandize it, we will have moved closer to achieving the goal of appropriate land use.

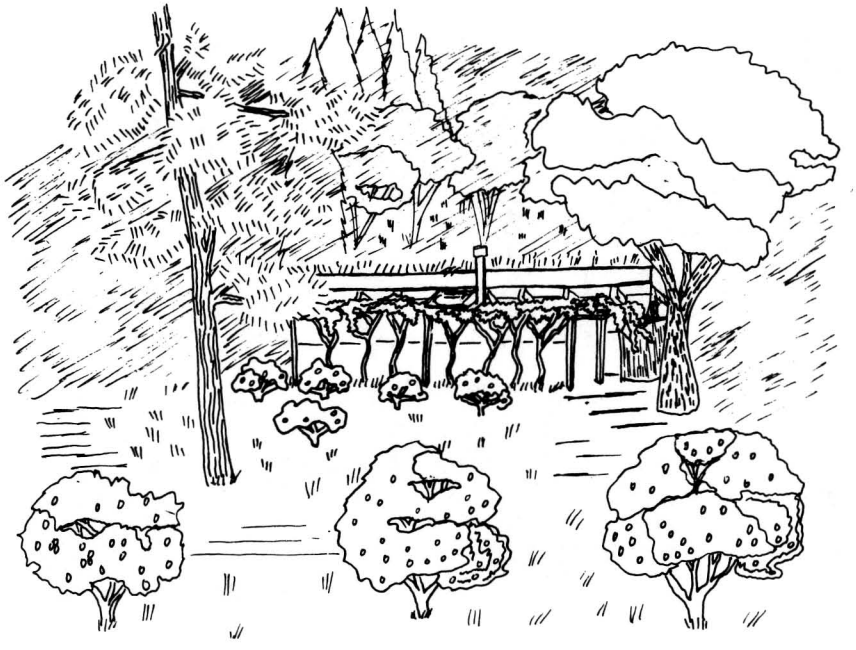


FIGURE 5.80 Landscaping began by preserving large native trees during the excavation of the steep hillside. Arbor in front of the house will support grapes, creating a shaded canopy for the walkway and greenhouse in the summer. Genetic dwarf fruit trees will produce well in the tempered microclimate near the house. Orchard and garden thrive in the arable valley below.

MOVABLE INSULATION

The installation of movable insulating shutters on the clerestory windows provided us with a surprise during this past winter: thermal performance of the house improved dramatically. The panels also dampened interior sound, creating quiet, and improved the indirect lighting by their reflective underside.

Low cost, simple maintenance and ease of manipulation were the design goals. The shades were construct-

ed of 3/4-inch rigid styrene board placed inside a cloth cover, much like a pillow in a pillow case. The open end of the cloth case was placed at the top. A wooden trim strip 3/8-inch by 1/inch by the length of each shade was nailed over this top side securing it above the window. The panel hinges on the cloth of the cover. The batten was secured by 3 five penny finish nails so it could be taken down easily, the foam board removed from the cover, and the cover washed.

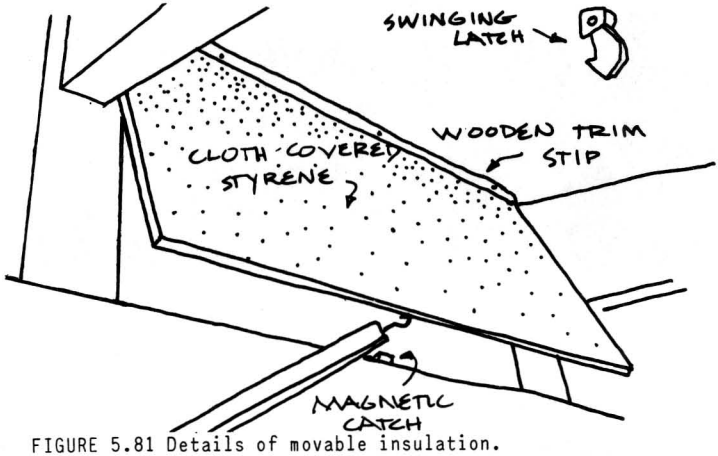


FIGURE 5.81 Details of movable insulation.

The side of the cover facing the window was white, reflecting summer heat out. When open on a winter day, the white surface increased interior indirect light by reflection. The other side of the cover was dark decorative material, seen from the interior on winter nights and summer days.

The catch which keeps the panel open was made of wood. Designed to work solely by gravity, the latch is pushed back by the opening motion of the panel, and falls of its own weight back to hold the panel open. This wooden latch is tapped back to close the light weight panel, which silently floats down against the clerestory framing around the windows. An inexpensive magnetic catch designed for use in cabinets was installed to hold the panel tightly against the wooden framing.

The shades are easily manipulated from below by a pole with a hook in the end. The ten shades are lowered or raised in less than one minute, the most productive minute we spend each day for energy efficiency.

INTERIORS

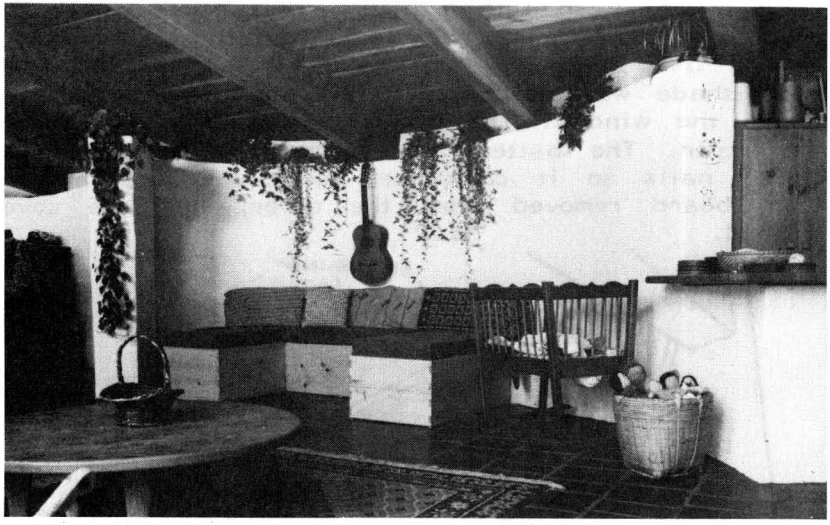


FIGURE 5.82 Curving walls define a comfortable living area, giving depth and division without walls to this long narrow house. Blanket boxes, modeled on a Shaker design, were built of homestead logged and milled 1 x 16 sugar pine boards. Each box provides eight cubic feet of storage and easily rearranged seating.

FIGURE 5.83 Cabinets and drawers from homestead Douglas fir, and sugar pine slab counter tops were built in 2 1/2-foot modules to easily fit against the curved walls of the kitchen. Cost for the cabinets was two and one half weeks labor and $150 for hardware, recycled particle board, and linseed oil.

CONCLUSIONS

We built a house that may last for centuries, and making final judgements after only two years seems premature. During the long months of construction, we experienced a range of conflicting emotions and attitudes about the underground space we were building, yet as we settle into it, we are able to draw some general conclusions.

Foremost is the recognition that this building is comfortable and works well in almost every way. It is warm and well-lit in winter, cool and well-shaded in summer. Ventilation is entirely adequate, and the structure did not leak when we recently experienced the wettest winter in a century. It performed well when deluged with 90 inches of rain and an accumulation of snow for over a month. Fuel consumption was very reasonable. We burned less than two cords of wood, half fir and half oak, during this winter which significantly exceeded the 4500 heating degree days which is normal for this location. Much of that supplemental heating was required by the large greenhouse and not the underground portion of the house. The sun provided most of the energy for our heating demands, which of course were low due to the earth sheltering. Electricity bills averaged less the $40 per month for our electric hot water heater, electric stove, refrigerator, 500-watt bathroom heater, incandescent lighting, and miscellaneous small appliances. Total construction costs for this house were $18,000.

During one heavy snowstorm, electrical power was out for almost five days, but we remained warm and comfortable. Our masonry wood stove generated so much hot water during this period that we bathed neighboring children whose homes were without hot water due to the outage. We cooked all meals on the masonry stove as well. Although many candles were burned and we used a generator to recharge the refrigerator once a day, this storm proved to us the value of this house in severe weather, as had a two-week hot spell the previous summer, when daily outside temperatures were well over 100 degrees Fahrenheit.

In short, our underground house provides comfortable living space. Its curving, white plastered walls and masonry stove remind many visitors of old Spanish buildings. Simple furnishings adapt easily to the curved walls of the house. House plants grow luxuriously on the ledge formed at the top of this wall. Interior

floor space is flexible enough for multi-purpose use, but is somewhat lacking in private space and storage closets.

Maximising the agricultural potential of our greenhouse may take several years. Yet, living with a garden in the house has been educational for us and the children; we can closely examine every aspect of life there. An aphid infestation was an opportunity to watch ants "milk" and herd their green "cows" and the kids loved spraying them away with peppermint soap. Although our young children often prematurely harvested our crops, we did grow chili peppers, parsley, herbs, chard, beets, and dwarf citrus trees in the winter greenhouse. Winter also brought the problem of excess condensation during prolonged periods of stormy weather, not unexpected for an uninsulated greenhouse in a cold, wet climate. Greenhouse management has been an enjoyable challenge.

Construction. In comparison to wood frame or masonry above ground structures, the construction process for this building was decidedly more work. Loads for underground construction are greater on walls and roof, and each structural member must be stronger and larger to accomodate those loads. Each stage requires more strenuous work.

On many levels, people often find owner-building an intense experience. Some begin the endeavor as an enthusiastic family only to end up divorced and broken hearted before the house is finished. Barbara, Ken, and his sister Evelyn Turner, a psychiatric social worker, studied and documented the many faceted responses of owner-builders to their projects in The Work Book: the Personal Politics of Building Your House. It might be wise to study the reactions of others before building a house. A house to be built underground will surely intensify the experience.

There may be other factors that may make your efforts more difficult. In our climate with our design, the bulk of exterior work had to be completed during the long, dry summer season so that the building could be backfilled before winter weather arrived. Rain would have caused the soil to slump into the work alley behind the house, complicating wall construction, waterproofing, and installation of the French drain. If large piles of earth behind the house had been consolidated by winter rains, backfilling would have been more difficult and time consuming.

Chance can come into play, as it did for us.

After finishing our excavation work, Otis cracked two ribs in an accident unrelated to house construction. This shortened our building season by six weeks, creating pressure to finish before the rains came and making work days longer and more strenuous.

And truthfully, anxieties were increased with our decision to build in civil disobedience to the codes. Stakes in this kind of gamble are high. When you have completed a safe and sanitary house, the process of eviction and condemnation is difficult and unpopular with county authorities, who are overburdened by other work. When a building is discovered during construction, a "stop work order" is issued, making each day of work thereafter a misdemeanor: the project is brought to a halt. If you are trying to shelter a growing family, this gamble with the building code authorities should be fully examined. Even if the hardship and heartache of legal disruption does not happen, the worry that it may will still be with you day to day. For us, the chance was worth taking; we have our home in the form we wanted at a price we could afford.

Despite difficulties and occasional bad luck, our house was closed in just in time to avoid the rains. The interior was completed that winter and the following spring. We have lived in our house for a year with much pleasure and satisfaction.

The biggest drawback of underground construction is that it is impossible to make preventive inspections and repairs of the earth-covered portions of the house. We would prefer to periodically inspect our home to make sure it is performing well. When a house is above grade, it is easy to catch a problem in its early stages. When the building is underground, its performance is considered acceptable until a full-blown problem arises, like a crack due to structural failure, a leak, or termite infestation. In any case, repair would entail enormous effort. The deeper the building is placed underground, the more difficult becomes the repair and the greater the destruction of landscaping. This problem will affect each owner-builder differently. We experience mild apprehension from time to time when we are unable to make the customary annual inspection. This feeling comes from intense curiousity: we want to see the myriad paths made by rainwater as it is diverted away from our house. These apprehensions and curiousities will likely diminish as years go by, and we will eventually learn to take the

normal functioning of the building for granted.

Now that we are settled in our house, the fact that it is underground seems less important to us. If we were to build again, we would likely not dig in as deeply as we did. Placing earth against walls and over the roof is aesthetically pleasing to us, and we benefit from the thermal protection. Yet, there would have been little difference in the performance of our building if we had not connected the berm and the sod. Waterproofing details would have been simplified, and lighting and ventilation would have been improved though they are adequate as they are. Excavation and backfill would have been easier. The isolation of the sod roof from direct contact with the ground soil would have have eliminated introduction of gophers and other pests from proximity to the roofing materials.

Toxic Substances. In our housebuilding process, a concerted effort was made to reduce or eliminate use of and contact with toxic substances. Yet we were surprised by the amount of toxic material we did use. Ironically, most of these materials came to us through our recycling efforts. The solvents and glues used to recycle the oak tile flooring were among the worst offenders. The epoxy used to build an inexpensive wainscoating of recycled wood around the recycled cast iron tub was also an unpleasant experience. The use of toxic substances has become routine in modern building procedures. Often the toxic manufacturing process preceeds the installation of a ready-made product and the purchaser may ignore the ecological implications of a product. Since we did most of our work ourselves, we saw and felt the toxic nature of some of these building materials first hand. We authors are at present working on a book outlining the toxic hazards found in both the process and final product of the owner-built home. Please fill out and send to us the question blank found at the end of the book if you would like to be contacted when the text is complete.

Another indoor pollution problem is being tested in our home---radon. Radon is the radioactive gas released by the breakdown of radium, and is produced normally in soil, rock, sand, slate, as well as masonry building products. High radon levels have been discovered in some above grade energy efficient houses that have low air change rates (1/2 per hour or less). Some levels were rated as carcinogenic as smoking a pack of cigarettes a day.

Earth sheltered housing may compound this problem. Underground houses use radon-producing building materials in their heavy construction, are covered by radon-producing soil, and may be suspected of higher concentrations. A radon monitor now hangs in our house for a three month test period. Results of this test will be published in future editions of this book, or write us for the findings of our on-going investigations of healthy housing/toxic housing. Because in our design we allowed reasonable infiltration of air just to assure freshness, we do not expect dangerous levels of radon in this house.

Skills. While it is true that both of us (Jane and Otis) have had commercial carpentry experience, that fact should not discourage owner-builders who have not developed building skills. Most of the skills for low cost building were unfamiliar to us, and we found ourselves developing new ones during the construction of this house rather than relying on our previous experience. Below is a chart of the skills we used to built this underground house compared with those we had used in conventional house construction.

No previous experience	fewer than forty hours experience	commercial experience
chain saw milling	hand mixing and pouring concrete	concrete (transit mix)*
welding	plastering	stud framing*
stone masonry	plumbing	timber framing
ferrocement	wiring	conventional finish carpentry
fiberglass and epoxy	soil cement brick	roofing*
slip form concrete		concrete block laying
surface bonding		adobe*
		sheet rock*

*skills unnecessary for construction of Mullan house.

Overall, we are content with our underground home. There are unique problems and anxieties peculiar to earth sheltering that we have tried to bring forth in our story of building this house. We have built durable housing that may last well over a hundred years. We wonder, having made such a permanent statement, whether this house will meet the needs of the future. Little more than a hundred years ago our nation fought the Civil War, and we now have no intention of building houses like those of that era. What will our great grandchildren think of our project?

Chapter 6

The Kern Studio

The single greatest impediment to people's acquisition of adequate housing is that it is viewed as a product, as the house, as an end in itself and not as an on-going process. Until builders, brokers, bankers, and consumers come to think of sheltering as an activity---as a verb rather than as a commodity, a noun---can we expect improvement in the present housing situation. Considered solely as a product housing, like other vital commodities, will continue to be supplied to the public by those mindless, mechanized means common to all production lines.

Most countries in the industrialized west are tooled-up to supply people with mass produced housing. Standardized components are manufactured and transported to building sites where they are rapidly assembled with power equipment. Those who will live in these buildings have no more input for the design or construction of these dwellings than they have for the way their food is grown or the way they get to their work each day. Factory-produced housing, like food and transportation, is part of an infrastructure of high finance, international marketing schemes, and highly efficient means of production control that are possible only with total mechanization, organized distribution, and tight-fisted management policies. In this country, the modular and mobile homes industries are prime examples of this system.

Expensive factory-produced interior finish materials and appliance installations account for about half of a home's total cost. The structural shell accounts for perhaps another quarter, while land and utilities share the remaining quarter of its cost. Thus, priority is clearly locked into those factory prescribed and produced elements on which the overwhelming majority of our people have become so dependent, from plumbing and electrical fixtures to labor saving appliances and automatic indoor environmental controls. Much of our notion of progress for the betterment of human existence is predicated on the desire and need to control

environmental living conditions. Modern dwellings reflect this concern for mastery and dominance over natural elements. In this country, for example, to operate home air conditioning units for the three summer months of the year, we use the same amount of electrical energy used by China, which has four-times our population, for all of its country's power needs. One result of our insatiable appetitie for luxurious surroundings is that a goodly portion of the world's resources are now devoted to our consumption of non-essentials.

Eventually, this view of housing as a packaged commodity will destroy people's access to single family dwellings, one of our most basic and precious social institutions. This will occur, not as a response to a popular awakening to a healthier more responsive housing ethic, but simply because too few of us will be able to afford the initial high cost of manufactured housing components and materials. For this privilege the world's finite resources will be wasted in the name of planned obsolesence. One day soon, rampant consumerism and the squandering of non-renewable resources may come to be considered a punishable crime when perpetrated against future generations. Those who persist in building complex, costly structures may well be brought to the simple justice of peoples' scrutiny and retribution. Every year in this country, each of our 70 million households uses 200,000 gallons of water and produces 3 tons of garbage. This not only has to stop but it assuredly will stop: future generations will see to that!

A more dynamic, life-supporting synthesis occurs when a house-building project is viewed as an intimate human process of shelter making. When the producer and the user are the same person, design and construction are directly linked and vitally affected. A building is then more likely to satisfy occupant's needs and desires because its builders can exercise maximum freedom of expression and discretion. As this non-specialized participant becomes engaged in the building process, work integrity is made manifest. Inherently, there is no separation between the manual, intellectual, and artistic aspects of self. Only demands of the building site, the climate, and the personal requirements of the owner-builder must be met. In this freedom oriented design-and-build process, new relationships with the ecosystem are initiated. Automatically, energy and material resources are conserved instead of squandered.

House building progresses much like that of the ecological succession of plant life, from weeds, to brush, to forested climax growth. In like manner, house construction should grow and develop. From a simple, basic core unit that adequately but modestly serves people's basic shelter needs, the house can gradually, with alterations and additions, come to correspond to the growth and change taking place in the lives of its occupants.

The term "industry-produced housing" best describes the product-approach to homebuilding. The one we use to describe the owner-built, low-tech, energy-conserving housebuilding process is "responsive building," a term originally suggested to us from the title of a 1972 shirt sleeves session of discussions that took place at MIT, called Responsive Housebuilding Technologies.

Responsive building, in our view, is that process by which shelter is built with hand tools and personal involvement, entirely abandoning the use of pre-made components, use of high-speed machine technology, and the labor of the uncommitted professional tradesman. The housebuilding experience should respond to the builder's touch and perceptions. Materials, like stone, wood, and earth, are more suitable for this sort of craftsmanship than are steel, plastics, pre-formed composites, and chemical synthetics. Gently curving architecture not only is structurally stronger than wood frame buildings but curved structures appeal more to our aesthetic sensibilities than those with crisp corners and unrelenting straight lines. A few, select materials fastened together in a simple manner will better satisfy housing needs than massive, complicated components fastened by methods not readily understood by the lay builder. An owner-built hand-crafted house meets the criteria for responsive building better than any that is manufactured. It is less expensive to build and the responsive process is healthier for all of those involved.

Our Underground Project. Recently completed, our earth sheltered studio building has a full complement of affirmative design features. Owner-builders who intend to duplicate any of our measures must first try them for themselves by constructing a small outbuilding prior to erecting a larger dwelling. In this way, too, the builder will become familiar with the concepts, materials, and methods of construction, thereby influencing both subsequent building design and construction.

We chose to build our studio below ground for

some familiar reasons and a few unfamiliar ones. Those that are customary include the fact that building underground tempers indoor climate, dramatically reducing expenditures of energy for heating and cooling a structure by tapping the near-constant subsurface earth temperature below ground. Too, earth which acts as an insulator will slow the transfer of heat from the interior of a building to the outside and protect the structure from the rapid dissipation of either precious heat or coolness, depending on the season of the year.

Our region of the country, the arid southwest, experiences its share of daily and seasonal temperature extremes. The use of large amounts of insulation for house walls and roofing may be warranted in climates seasonally more extreme than ours, but here we can benefit more by the use of thermal mass to enclose our structures. Heavy applications of manufactured insulation will prevent much of the flow of heat energy through a wall. A wall or roof insulated by thermal mass, such as earth, will only delay that flow. High mass (dense) masonry materials, which are poor insulators, ultimately fail to confine the natural flow of energy from areas of warmth to those of coolness, although density or mass gives a wall or roof the capability of storing large quantities of heat for longer periods of time. By covering a building with earth, you succeed only in increasing the time lag for heat flow between warm interiors and colder exteriors. The advantage of using earth's thermal mass to insulate a building is that indoor temperature is not significantly influenced by daily changes in the temperature of outside air. Like the traditional thick-walled adobe building, the earth sheltered building tends to hold a nearly constant temperature, day and night, summer and winter. This is not the case with heavier insulated above-ground structures. Thick insulation may give it a certain resistance to heat loss for a while, but this material neither absorbs nor delays the eventual movement of heat from the area of high pressure (indoors) to the area of low pressure (outdoors).

For creature comfort here in the southwest, then, given adequate ventilation thermal mass functions as well as manufactured insulation. Only a nominal amount of insulation was used in the walls of our studio building, mostly to prevent surrounding earth from acting as a heat sink and drawing heat directly through walls into the earth cover.

Site and Soil. Another reason for building our studio underground involved our site and soil conditions. Soil on our south-facing and steeply sloping site was a sandy loam over deeply buried granite deposits. Exposure and drainage were excellent, two conditions essential for building underground. In our arid clime, we are plagued with fire danger and earthquake is an ever-present threat. By placing our structure into rather than upon the ground, both quake hazard and fire danger were minimized. Our use of masonry building materials further made conflagration or destruction unlikely.

Costs. To build conventional underground housing with contemporary methods and materials requires an investment in excess of that used to build the same kind of housing above ground. The structural detailing required is more complex. Additional labor and equipment are necessary. Much energy and expense must compensate for externally applied forces and the internal stresses inherent in building materials that impinge on an underground structure, reactions not encountered in above-ground building. When designing our studio, we actually used ground force to stiffen and strengthen the shell of our building. Thus we were able to use less material to do more structurally. Underground building is neither structurally viable nor affordable if it requires the use of greater quantities of building materials, more labor, and greater sums of money to achieve its successful construction.

Design Criteria. Prior to building, we spent some time evaluating our design needs, as follows:

1. The primary function of any habitable structure, whether home, school, or workplace, is to provide an indoor environment or microclimate in which human health, well-being, and safety are enhanced. We wanted a quiet place in which to work, one with ample natural lighting during daytime hours and adequate natural ventilation. We intended to heat with wood and to use only natural ventilation for summertime comfort. All floor, wall, and roof coverings were to be of materials with the capacity for delayed air and moisture exchange with the outside. No materials would be used that would inhibit building membranes (walls or roof) from "breathing," from transferring air or moisture vapor to the outside. Any materials that would outgas harmful substances into the indoor atmosphere were to be avoided as much as possible. Use of all polyvinyl synthetic polimers, ureaformaldehyde-

based wallboard coverings (plywood or particle board), commercial insulation products, and plastic vapor barriers were to be avoided.

2. Assuming that most people have the innate capacity to build their own homes, and should therefore do so, we felt that we should be able to do so without also incurring a lifetime burden of debt to acquire housing. For this reason, too, we kept our project requirements simple enough so that it would be entirely affordable. (Excepting our labor, we invested little over a thousand dollars for 350 square feet of floor space.) The trade-off for low capital outlay, of course, was erecting an experimental building with hand tools and techniques. Admittedly, this would make our project a labor-intensive task. However, our use of local materials would require only minimal on-site processing and would eliminate our use of expensive manufactured building supplies. We would prefer to invest, instead, our more plentiful time and labor in lieu of fewer, less abundant dollars.

3. We wanted our building to be structurally sound and durable, easy to operate and maintain, resistant to the vagaries of climate and general deterioration.

4. Our building should be pleasant to behold, its artistry expressed in line and form, color and texture, balance and movement, and in the character

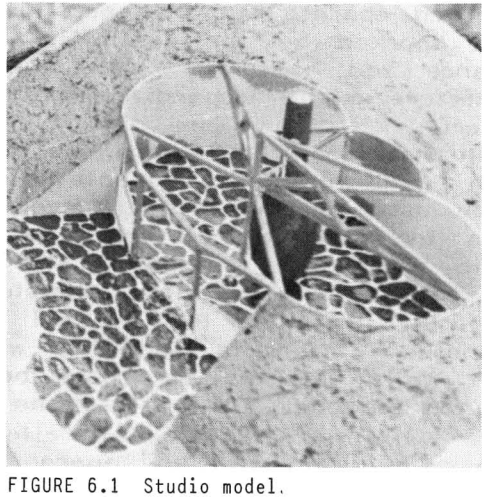


FIGURE 6.1 Studio model.

and quality of the finished structure. These elements of artfulness would be especially important in this studio where we hoped our creative energies would find release. As we prepared preliminary sketches and a study model of this building, we repeatedly asked ourselves: will it be healthful, economical, durable, aesthetic?

Other Design Factors. We feel the ideal building form is the egg shape. For this reason, we used curvilinear, thin-wall construction for the walls of our building. Earth forces, pressing against these walls, were resisted by this curved shell. Despite the strength of this form, modern engineers seldom use it for wall building since they have no practical method with which to cast or build this kind of wall. Traditionally, walls have been and continue to be formed of straight pieces of wood or with rectilinear masonry components, like brick or concrete block. The result is that most modern buildings have flat plane surfaces and squared or angular corners. Roofing is tilted diagonally to give the resulting boxy structure a "progressive" or more "modern" appearance.

People in the building trades also resist building curved shaped buildings because any deviation from established patterns of construction requires many changes in method and ultimately costs more money. There are likely many contractors who would really prefer to build curved wall structures for a large number of homeowners who, in turn, would relish living in curved spaces, but the speculating building contractor is spooked by the possibility of customer sales resistance and homeowners fear that unconventional architecture might jeopardize the resale value of their property.

The Slip Form. Some years ago, we began experimenting with a lightweight, movable building form that could be used to cast either curved or straight wall sections for masonry buildings. We called this device a slip form since it is slid along to a new position once the building material (concrete) is packed in the form. In time, this tool evolved into a form that simultaneously makes a sandwich wall of two, parallel thin walls with an air space between these inner and outer sections. The two sections of wall are held together with galvanized metal clips, and the inner air space is filled with any appropriate insulating material.

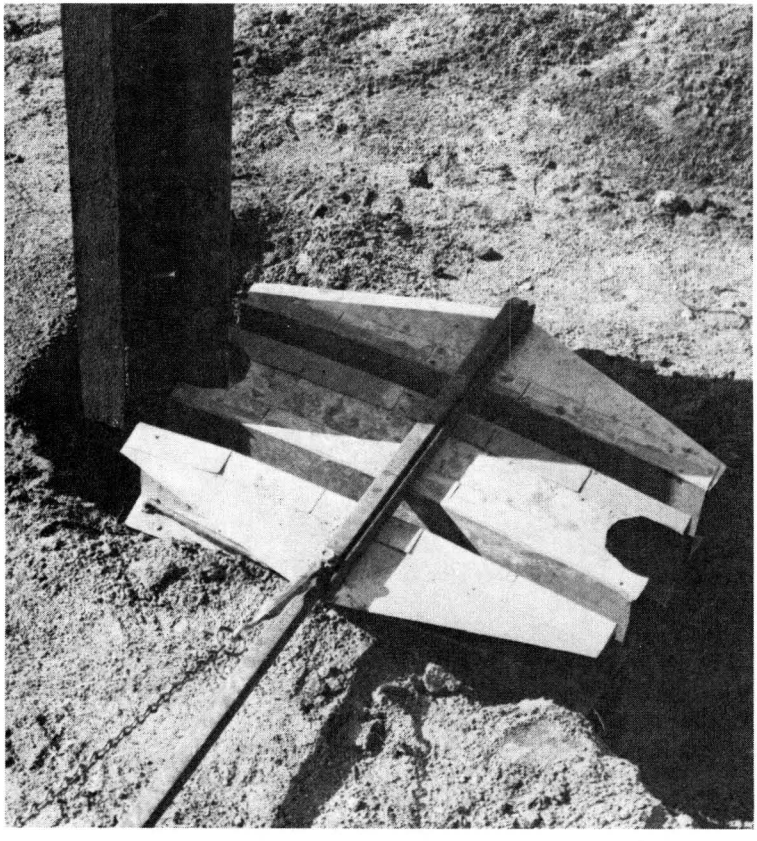


FIGURE 6.2 Slip-form at beginning position.

Wall Construction. The curving masonry walls of our building are entirely self-supporting, since each roof beam is supported independently on a column of pipe embedded in the concrete wall. These walls rest on a footing of crushed rock. To reinforce or stabilize them, we pour a concrete bond beam at the base, mid-point, and top of each wall. Two 3/8-inch steel rebar are placed horizontally in each course of bond beam. A 12-inch length of 3/8-inch rebar passes through a hole drilled in each pipe support to connect sections of the bond beam as it passes around these support pipe. This securely anchors pipe supports in the wall.

1. To begin work, the floor area must be graded and leveled. The center radius points from which the

form's rod will swing should be determined. See illustration. At each of these two points, plumb and set in concrete a 2-inch pipe that is a few feet longer than the wall is high.

2. Once the pipe is firmly set in this concrete base, place the end of the guide arm over this pipe and scribe an arc with the slip form to locate the position of the wall footing. As the slip form moves along its prescribed path, scratch a mark with a nail or sprinkle lime along the ground. This will indicate the inner boundary line for foundation work. From this line outward, dig a trench 16 inches wide and 6 inches deep.

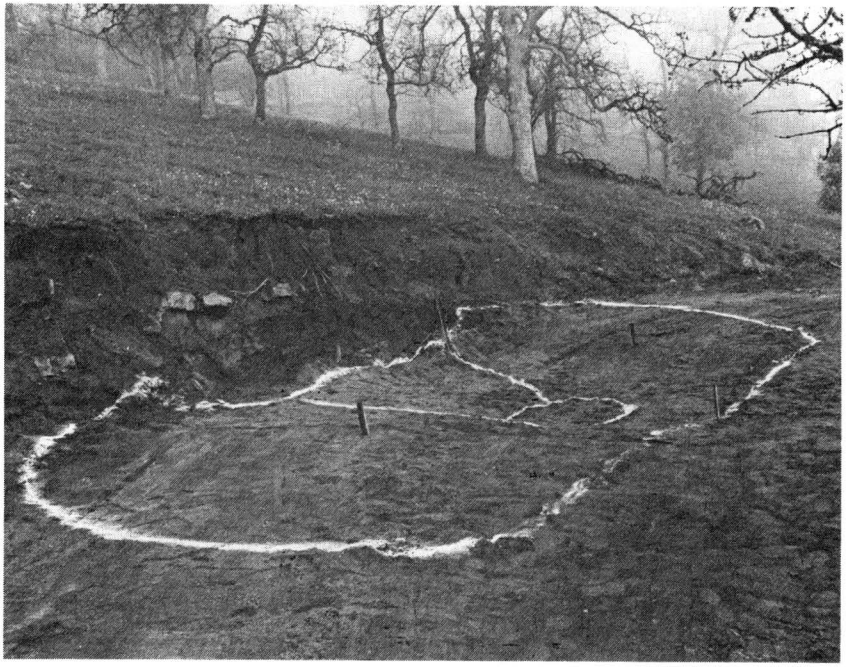
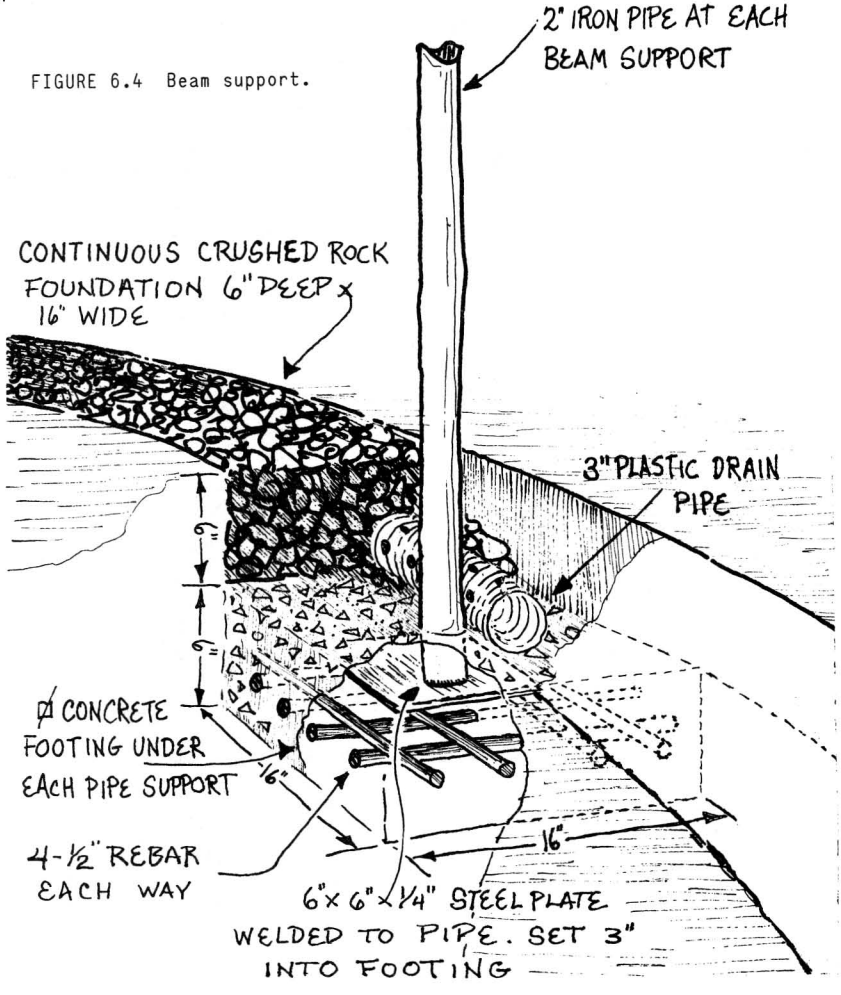


FIGURE 6.3 Foundation layout with lime.

3. The slip formed walls terminate at either side of the south wall of the building, against a 2 x 8 board that is creosoted, plumbed, and braced in position. Bent and rusty nails, driven partially into this board, will help to bond the board with the concrete wall.

4. Again, using the slip form for alignment, locate placement of concrete pads that are the base for vertical pipe that, in turn, support beams for the roof. These pads are 16 inches square, and they are dug 6 inches deeper than the base of the footing trench. Into this depression, pour 3 inches of concrete. Lay 4 pieces of 3/8-inch steel rod horizontally in each direction. Pipe supports for the roof are set on these rods, and after they are carefully plumbed, they are braced in position. A steel plate, previously welded to the bottom of each of these upright columns of pipe, supports the pipe while an additional 3 inches of concrete is packed around them, filling the pad hole.

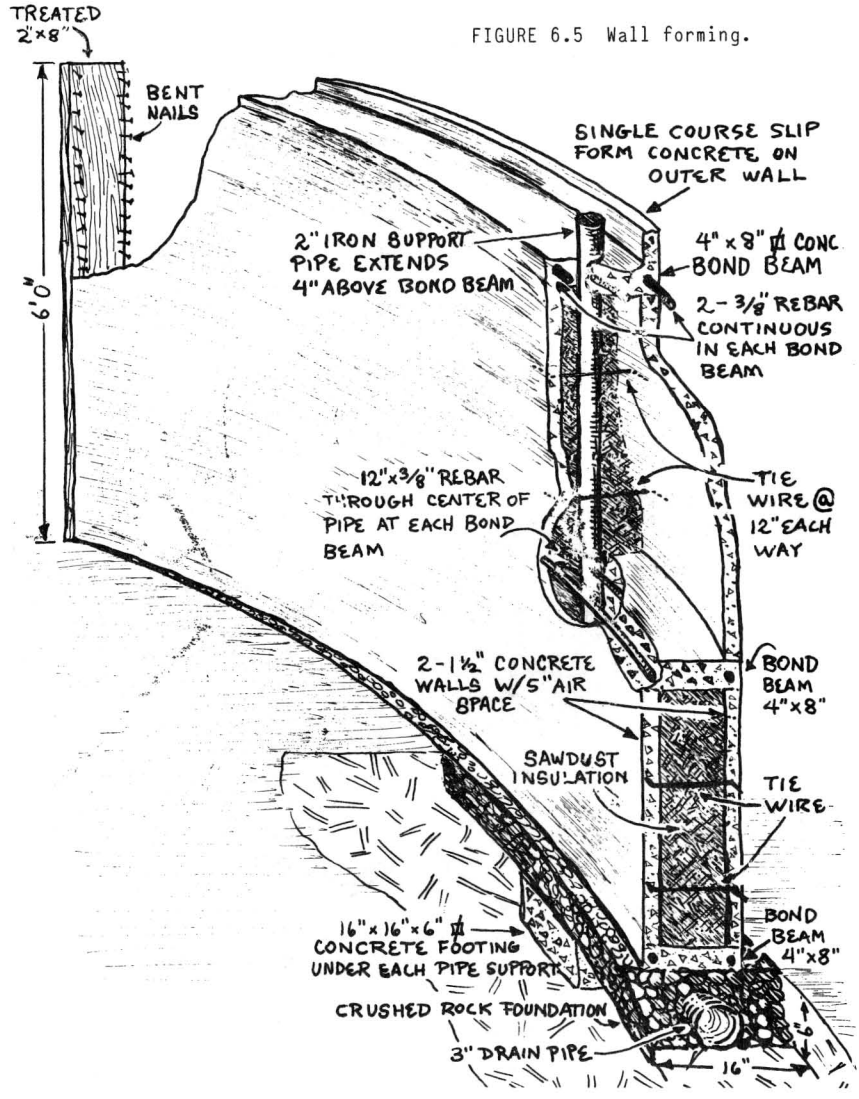
FIGURE 6.4 Beam support.


2" IRON PIPE AT EACH BEAM SUPPORT
CONTINUOUS CRUSHED ROCK FOUNDATION 6" DEEP x 16" WIDE
3" PLASTIC DRAIN PIPE
6"
6"
CONCRETE FOOTING UNDER EACH PIPE SUPPORT
16"
16"
4-½" REBAR EACH WAY
6"x 6"x ¼" STEEL PLATE WELDED TO PIPE. SET 3" INTO FOOTING

5. A continuous 3-inch plastic drain pipe is laid along the center line of the foundation trench, around the beam supports, and the footing trench is then filled with crushed rock to a height that is level with grade stakes in the trench.

6. Remove the center core of the slip form and cast a bond beam the full width of the wall, directly over the gravel in the foundation trench. Place two 3/8-inch steel bars midway in this beam as you form

FIGURE 6.5 Wall forming.


TREATED 2"x8"
BENT NAILS
6'0"
SINGLE COURSE SLIP FORM CONCRETE ON OUTER WALL
2" IRON SUPPORT PIPE EXTENDS 4" ABOVE BOND BEAM
4" x 8" ⊓ CONC BOND BEAM
2-3/8" REBAR CONTINUOUS IN EACH BOND BEAM
12"x3/8" REBAR THROUGH CENTER OF PIPE AT EACH BOND BEAM
TIE WIRE @ 12" EACH WAY
2-1½" CONCRETE WALLS W/5" AIR SPACE
BOND BEAM 4"x8"
SAWDUST INSULATION
TIE WIRE
16"x16"x6" ⊓ CONCRETE FOOTING UNDER EACH PIPE SUPPORT
BOND BEAM 4"x8"
CRUSHED ROCK FOUNDATION
3" DRAIN PIPE
16"

it. At each juncture with a vertical pipe support, insert a 12-inch length of 3/8-inch rebar through a pre-drilled hole in the pipe.

7. To form curved walls, replace the center core in the slip form. Then cast a single layer of double wall atop the freshly poured bond beam. This casting must be one continuous course to prevent a "cold" concrete joint between the bond beam and this first course of wall. Across each subsequent layer of formed wall, at 2-foot intervals from beginning to end, place Z-shaped No. 9 or heavier, galvanized tie wires. As you progress upward with layers of wall, stagger placement of these ties vertically. Occasionally, fill the wall cavity with sawdust or other insulation (perlite, vermiculite, etc.) level with the top of the wall.

8. At midpoint in the construction of your wall, again remove the core of the form and cast another bond beam reinforced with 2 bars of 3/8-inch steel rod. Resume slip forming the wall and cast the final, upper bond beam, again with the appropriate size and number of reinforcement rods. We finished the top surface of the bond beam at a height of 6 feet above ground, measuring from the base of the lower bond

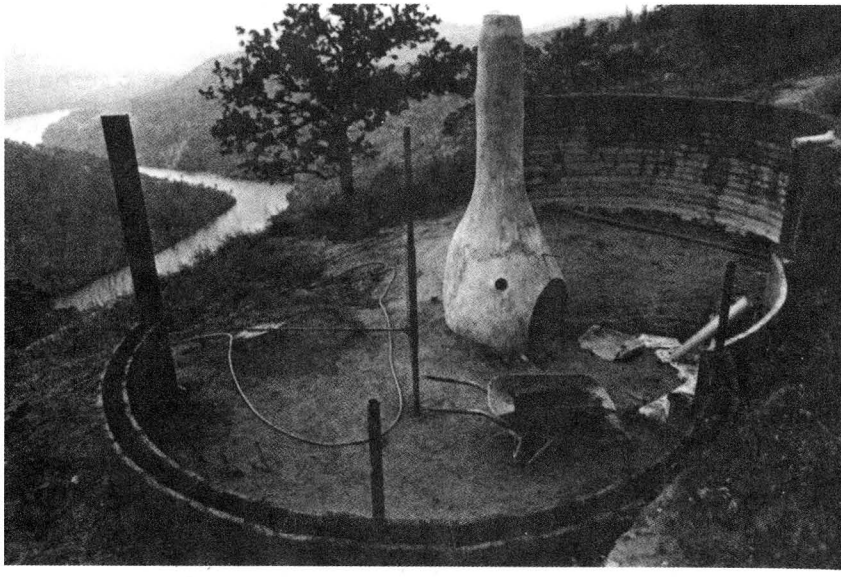


FIGURE 6.6 Slip-form walls under construction.

beam. This gave us a ceiling height of 6 feet at the juncture of wall and roof, above some book shelves. For structural considerations, we built our concrete walls not over 6 feet in height and avoided cutting any window or door openings through them. If you are taller, you may wish to increase this height by another course or two of wall.

9. A single layer of outer wall is cast atop the upper bond beam to act as a stop or as blocking for roofing material, which will butt against it. This completes the wall-building phase for this underground structure.

Waterproofing Walls. The slip form process creates a rough wall finish over which a coat of plaster may be applied to either side of the exposed surface. Smoother surfacing makes it easier to apply waterproofing material before earth is backfilled against the outer side of the structure. A smoother interior wall surface may be more appealing for some people as well. We happen to like the rough, untouched surface formed by the construction process. Rather than apply common plaster, however, which contributes little to the structural integrity of the wall, we recommend applying surface bond plaster, a fiberglass-reinforced, cement-based material that will bond the thin concrete shell of the building into a homogeneous whole. Customarily used to coat concrete block that have been laid up dry without mortar, surface bond is ideally suited to unify the porous layers of this wall. When purchased in its component parts, it is relatively inexpensive. It may be mixed in a wheelbarrow with a hoe right on the building site. Both sides of a concrete slip form wall should be plastered with this material. Apply the material as thinly as possible to a previously dampened wall surface. Refrain from excessive troweling, which will weaken the bond. It is also important to cure the coated wall with a mist of water sprayed on its surface to prevent rapid dehydration and the cracking of this masonry material.

Surface Bond Mix. To make a 25-pound batch of bonding mix, first thoroughly mix 19-1/2 pounds of Portland cement, 3-3/4 pounds of hydrated lime, and 1/4 pound of calcium stearate (available from a chemical distributor). Cement in this mixture provides strength, lime makes the batch workable, and calcium stearate makes it waterproof. To this dry mixture, add 1 pound of 1/2-inch lengths of glass fiber filament. Dealers in plastic products can supply either a

type E fiber or, better, a type K fiber that is alkali-resistant. These glass fibers provide reinforcement and prevent the cracking of the material. In a separate container, dissolve a 1/2-pound of calcium chloride in 1-1/2 gallons of water and, stirring continually, slowly add this wet component to the dry ingredients. The calcium chloride causes the compound to set up rapidly.

Framing. The only flat vertical surfaces on our building are its south wall and the upper, roof level clerestory window-wall. Both sliding glass entry door and the clerestory windows provide the building with natural light and ventilation. The remainder of the south wall is fixed glass. Since this wall in non-load bearing, a single creosote-treated 2 x 4 plate is embedded in a thin pad of cement, which in turn rests on a footing of crushed rock. To insure that the plate will be securely anchored in the concrete pad, bent nails are partially driven into its underside. Standard-sized 4 x 4 post framing is erected alongside the glass door and the windows on either side of the door. Above and below the windows, plywood is nailed to these posts, forming a 4-inch-thick wall cavity that can be filled with sawdust insulation. At the point where the curved ceiling intersects with this flat, south wall (above the windows), the top of the plywood paneling is scribed to match the curve of the roof. Except for exterior waterproofing, this completes the wall-building phase of this project.

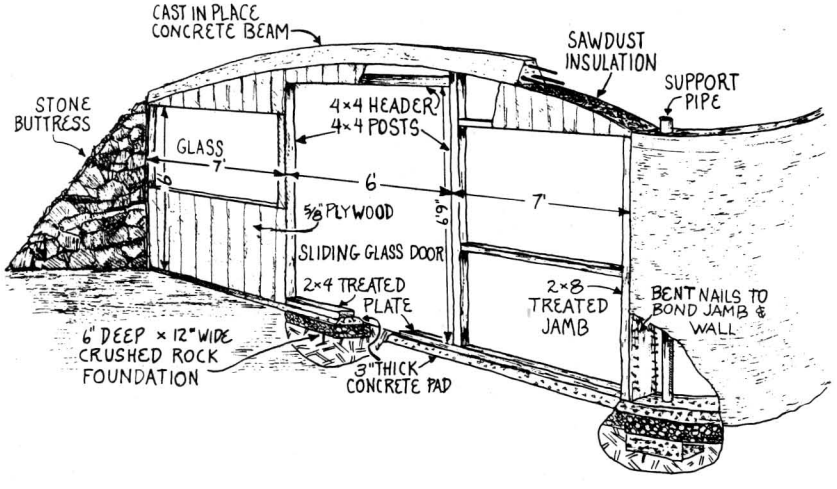


FIGURE 6.7 South-wall details.

FIGURE 6.8 South-wall construction.

Water Pressure Against Walls or Roof. Rain-saturated earth will exert considerable pressure against an underground building; specifically, 62.4 pounds of pressure per square foot for every foot of depth. Our 6-foot-high walls, therefore, must bear 374 pounds of pressure for each square foot at the base of the wall. Being curved, they satisfactorily withstand this force, but as an additional precaution, we designed the floor and roof systems so that they would brace the wall. At the same time, loading pressure from the force of earth bearing against these walls contributes to support of the roof. Curved horizontal and vertical wall, floor, and roof surfaces work together to create an integral whole.

Composite Materials. The roof beams for our studio were inspired by a photo showing Nigerian builders erecting wattle and daub roof beams for the primitive curvilinear structures they have intuitively built for centuries. The flowing, graceful curvature of these structural members is appealing and impressive. Made of clay and sticks, this hybrid building construction probably originated in Egypt. When the best properties of two or more materials are combined to make a superior product, the resulting material is said to be a composite or hybrid. The Egyptians made composite

building units of clay and straw which, when sun-dried, made adobe brick.

FIGURE 6.9 Wall bracing with concrete beams.

FIGURE 6.10 Traditional wattle and daub beam construction.

Another example of composite construction involves enmeshing steel bars in concrete. This product is stronger than either steel or concrete used by itself. If a wooden member is anchored to the lower edge of this kind of beam, shear and tension values can be enhanced. Concrete, in its plastic state, is easily molded in a curved shape. When set, it has high compressive strength. Wood has flexibility and absorbs impact and overloading for short duration without failure. Both wood or unreinforced concrete have a creep or stress characteristic of about the same order of magnitude. This, however, is not the case for a composite member made of steel and concrete, which can crack under longterm loading.

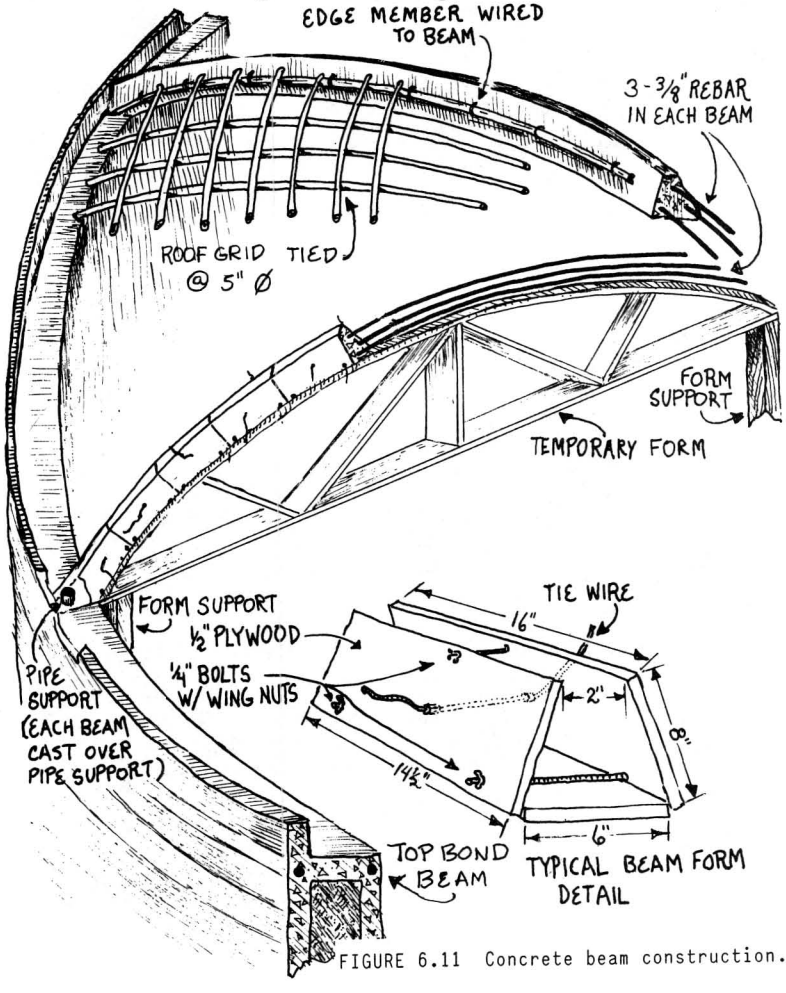


FIGURE 6.11 Concrete beam construction.

Roof Beam Spans and Reinforcement. All roof spans for our studio building measure less than 14 feet in length. We embedded 3 3/8-inch steel rods in each arching, triangular-shaped beam of concrete. Roof strength was thus sufficient to support about 20 tons of roofing material. To cast these composite roof beams, temporarily anchor a curved wooden form between the two bearing points for each beam. In our building, a centrally located concrete-reinforced fireplace/stove provides bearing for all roof beams. Exterior bearing is carried at the top of each of the 2-inch pipe supports embedded in the curvilinear walls.

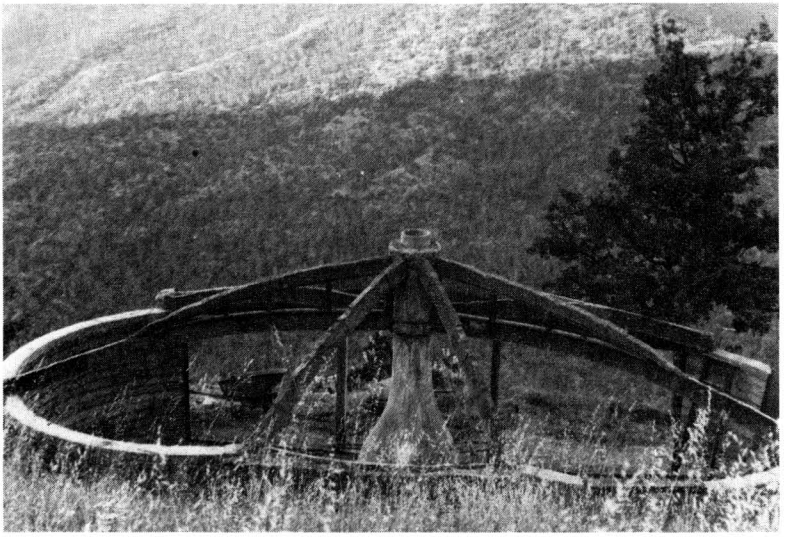


FIGURE 6.12 Ready for roof surfacing.

Forming Roof Beams. A series of side forms, made of plywood, are bolted in place along the arching wooden form for the roof beams. Tie wires pass through these forms. Later, they will be used to anchor a roof gridwork of bamboo that will carry various plasterings of clay roofing material. As each beam is progressively cast, a new pair of side forms is bolted in place, ahead of those already in place. Two reinforcing rods of steel are laid along the length of this form and are cast in concrete. A third steel rod is pressed into fresh concrete at the top of the pour. The casting of roof beams continues until all of them have been formed.

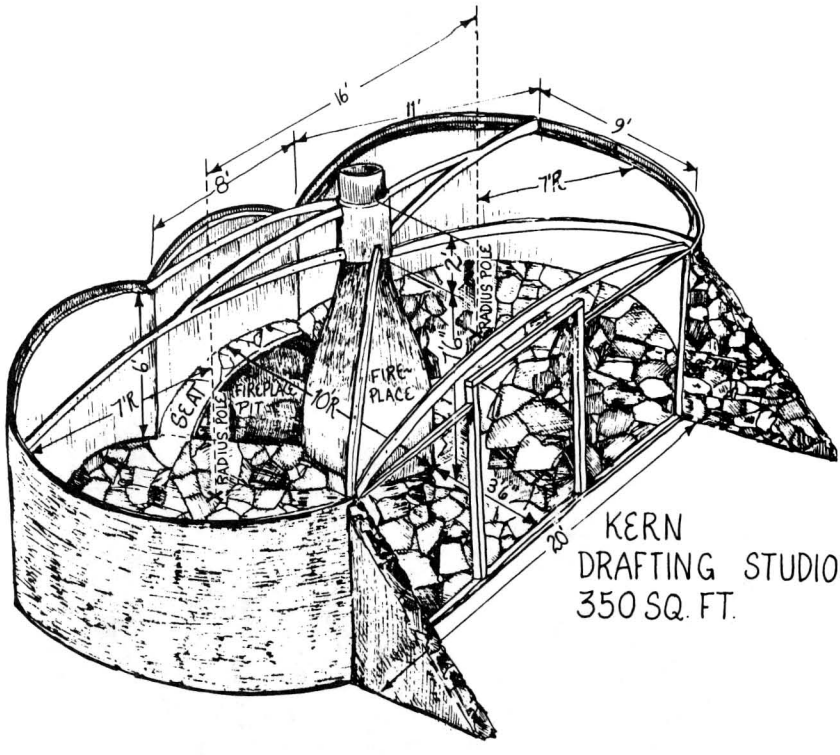


FIGURE 6.13 Roof construction detail.

It is important to thoroughly pack wet concrete around the steel rods and to tamp it against the side forms. Vibrate all three sides of the form and the steel rods by tapping them with your trowel. To improve the strength of the batch, mix the concrete rather dry, at a ratio of 1-part cement to 6-parts of a blend of aggregate that is half sand and half pea gravel. The plywood side forms may be removed a day or so after the pour, when the concrete beam is firmly set. The roof beam spanning our south wall was a longer length than we had forms to accomodate so, as the beam set up, these wide forms were removed and were leapfrogged ahead. This procedure enabled us to continue pouring the beam.

Two day's time is sufficient for a concrete beam to set up before removing the bottom support form from the finished beam. If all beams for the structure have the same length and curvature, the same arching formwork can be used to cast all of them. Beam

curvature is determined by using the formula in which the depth of the arch, at midpoint, is figured as 10 percent of the length of the span. The depth of our 14-foot beam at midspan was 17 inches. It is imperative that beams damp cure for at least two weeks. Sprinkle them often in dry weather. During this time, the roof grid may be installed and preparations may be made for casting the roofing material.

Clay-Bamboo Roofing. Like our arched roof beams, our choice of roofing was influenced by the work of indigenous builders. Possibly the commonest building method used by people throughout the world is to erect a grid or framework of woven sticks impregnated with earth. This pattern of construction is called "democratic," for when a load is applied to any part of the grid, deflection spreads evenly to adjoining members, equalizing the stress and minimizing the load along its sides. Edges of this grid must withstand the major impact of loading.

Using wires running through our concrete roof beams, we securely anchored all edges of the grid. One outer member of bamboo runs the entire length of the concrete beam. All crosswise, intermediate members of this grid, which are wired directly to the edge piece, transmit their load factors to the concrete roof

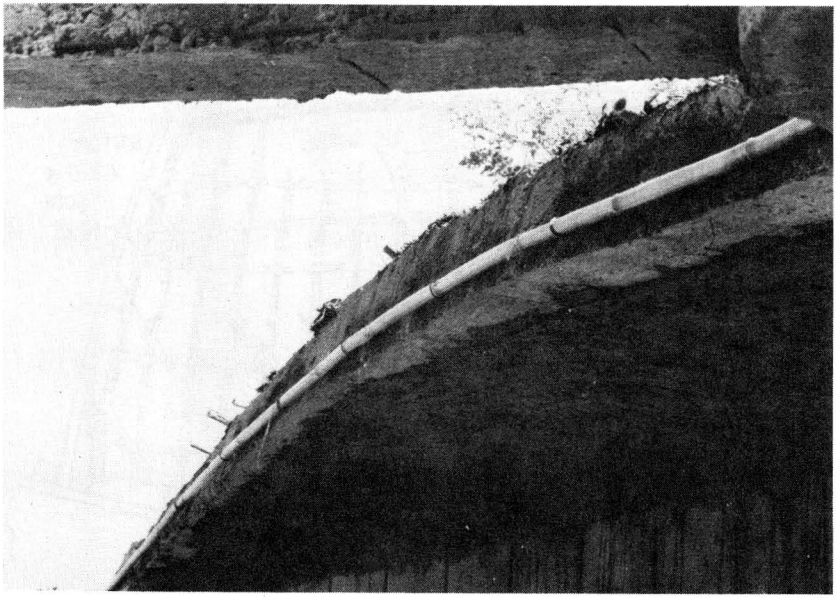


FIGURE 6.14 Edge support in place.

beams on either side of the bamboo grid. Each panel is triangular in shape, with one leg of its gridwork resting or bearing directly on the bond beam along the top of the wall.

A wide variety of materials may be used to weave this roof grid. From California's valley sloughs, we had an unlimited supply of free giant reed grass (Arundo donax), a form of low-grade bamboo. Dried Johnson grass, willow or mulberry limbs possibly may be used. The builder should experiment with local materials to learn what would work best and most safely for this task. One-inch-square scrap wood might be used for gridwork. The function of this framework is to carry roofing material that will be plastered over it. Whatever material you use to build this grid will be totally enclosed, protected from deterioration by air and moisture.

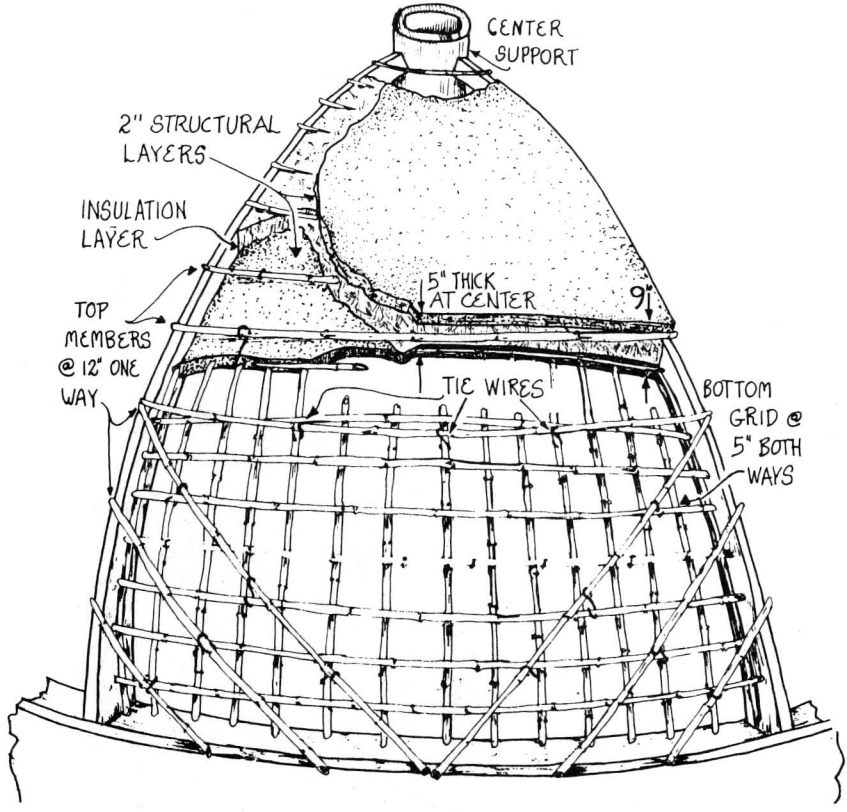


FIGURE 6.15 Roof panel construction.

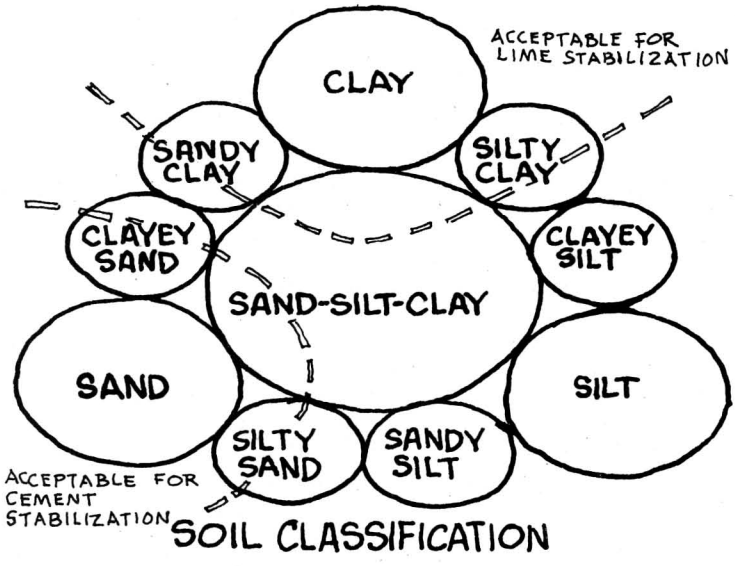


FIGURE 6.16

Properties of Clay and Sand. We decided to cover our studio roof with earth, a material used since earliest times. Only clay, in large part sand with firm grains that give strength to the composite material, should be used. A certain proportion of clay is necessary to bind or glue the sand particles together. Unlike sand, clay will shrink and crack when it dries, so a much smaller proportion of it should be used in this mix. These components, sand and clay, interact to form a composite material of structural integrity. Sand, which is inert, provides the brute strength for the material while clay provides the necessary plasticity or cohesiveness. When moist, sand by itself is stable, has a low rate of adsorption, and undergoes little shrinkage. Clay, by itself, expands greatly when moist and has a high rate of adsorption. Its high shrinkage factor causes excessive cracking.

Characteristics of Clay. Some clays have more plasticity than others and may be combined more successfully with a greater proportion of sand. All clays that originate from deeply buried sources of metamorphic rock are composed of silicon and aluminum. Those arising from granite are called kaolinite and are considered the purest and most stable of clays. The character of kaolin clay is stable and restrained; it expands little when wet and shrinks little as it

dries. The reason for this is inherent in the crystalline structure of this clay. It is coarse, not fine. Viewed through a microscope, a single crystal of clay resembles a flat plate, its face always aligned at a right angle to the direction of pressure. Given time, compressed clay eventually forms shale or slate. These plates are thicker in a coarser clay, like kaolinite, which therefore shrinks less. It is also less plastic than is fine clay.

Soil Test. To test the suitability of your soil for clay roof construction, place two cupfuls of typical soil sample, which has been sieved through window screen, in a quart Mason jar. Add two cups of clean water. Secure the lid and shake the jar vigorously for several minutes. Allow the mixture to settle. In an hour, you will begin to notice three distinct layers in the solution. The bottom layer will consist of coarse sand. Sandwiched between this layer of sand and a top layer of clay will be a strata of silt. By measuring the depth of each of these layers and dividing by the total depth of each layer, you can determine the percentage of each of these materials in your soil sample.

Properties of Clay with Sand. We have found that, although the proportion of silty clay to sand may vary considerably from locale to locale, various soils nevertheless remain satisfactory for building purposes. A sample should be not less that 1-part clay to 4-parts sand nor more than 1:1. As the proportion of clay in a sample of soil tends toward a minimum desirable quantity, which is 1:4, you will find that less stabilizer and less water are required. This can amount to a significant saving of money.

Asphalt Stabilizer. Bitumen is a general term used to refer to any of several kinds of hard or semisolid asphaltic residues that occur as natural deposits in the earth or that result from the distillation of coal tar or petroleum. For a bituminous material to combine with soil, it must first be emulsified (with water) so that it will mix with the water added to your roofing mix. Only 4 percent by weight of bitumen stabilizer is required for a proportion of 1:4, whereas 12 percent by weight of bitumen is required for a proportion that is 1:1. When more than 5 percent bitumen is used, the strength of the material decreases substantially. Bitumen, emulsified at the refinery, is suspended as fine globules in water. When mixed with soil, these asphaltic globules adhere to the surface of soil particles.

An ideal proportion of bitumen to water is 1:4 in a mix of sand with clay in a proportion of 1:4. Once dried, the composite becomes solid and impervious to moisture. Soil is thus "stabilized" because water cannot penetrate to the particles of soil. Like clay, bitumen also functions as a binder for soil. For this reason, any soil used should be fully pulverized in order for the bitumen to be uniformly distributed over each particle of soil to create a water barrier.

Grades of Bitumen. Commonly, there are fifteen grades of emulsified asphalt available for building use, and it is important for the builder to select the proper one. Some grades are medium setting (coded MS and CMS), while others are slow setting (coded SS and CSS). Still others are rapid setting (coded RS1 and RS2). Rapid setting emulsions are used to surface roadways where sealant penetration is desirable. Medium setting emulsions are reserved for central plant mixes in which coarse aggregates are included. The one we use is coded SS or slow setting, which means that the emulsion slowly separates back into asphalt and water to leave a film of asphalt on the grains of soil, the hallmark of the stabilizing process. A slow setting or "slow breaking" emulsion is preferable, because it separates only after being thoroughly mixed with soil. Freezing temperatures will also cause bituminous components to separate out. A storage container of bitumen should be covered to protect it during freezing weather.

The Asphalt Emulsion Association is a manufacturer's organization formed to promote use of this material. It has published a booklet entitled Emulsion Plants in the United States, a reference work helpful to those of you wishing to locate a source of asphaltic stabilizer in your area. You may write to this association at 1000 Vermont Av NW, Washington DC 20005. Ask for the address of a plant near you that sells SS1.

It should be noted that bitumen is an organic compound, usually found buried beneath dense layers of sediment. Asphalt, like other petroleum products, was formed long ago in earth's geologic past as a result of the anaerobic decomposition of plants and animals. In parts of the country where there is high humidity and many microorganisms in the soil that will be used for building purposes, bacteria may react with organic compounds of bitumen to cause a mold to form on the finished surface. Given time, this mold will lessen the bitumen's ability to waterproof the surface.

Adding Lime. One solution to the problem of mold formation is to reduce slightly the proportion of bitumen and add about 5 percent hydrated lime to the soil mixture. Some builders prefer to substitute Portland cement, which makes a composite material called soil cement. Both materials cost about the same on a pound-per-pound basis, but since lime is only half as dense as cement, it costs half as much to use. After extensive testing, we have found that a "pozzolanic" chemical reaction occurs between clay and lime to create a product that is far superior to that produced by adding only cement. Another advantage for the use of lime rather than cement is that smaller amounts give superior results. Unlike cement, adding greater quantities of lime beyond an optimum amount of 5 percent will not add any substantial factor of strength to a clay mixture.

The ancient Romans learned of the structural value of pozzolanic materials that occurred naturally. Before they made lime from limestone by firing it, they mixed volcanic ash and diatomaceous earth with clay and shale. When ash from furnace fuel (flyash) is available, it too can be used as a pozzolan to stabilize soil. A pozzolan by itself has no cementitious value, but as a finely pulverized siliceous material, it reacts chemically in the presence of moisture, clay, and the calcium compounds found in lime to form a brick-like building material.

Fibers. Another component of our stabilized clay roof is an organic binder. Early Egyptians learned of the structural value of straw or reeds added to clay. Some of their buildings are so well preserved that even the particular species of grass they used in their adobe block can still be identified today. We use dry, chopped, wild oats because of their availability on our homestead. Actually, any form of grass, sawdust, pine needles, or straw will suffice.

The addition of organic material increases the dry strength of clay. At a microscopic level, any cracks are seen to be more evenly distributed, increasing the tensile strength of the finished material. Embedded fibers aid the evaporation of moisture from inner portions of the composite material, allowing for thorough, consistent drying so that the forces of expansion and contraction are evenly distributed throughout the material. Most important, the addition of fibrous material creates pockets of air rather evenly distributed throughout the material, giving it greater thermal

storage capacity. Finally, by adding lightweight organic matter, the weight of this material when used as roofing is substantially reduced without sacrificing strength. This is an important factor in earthquake-prone areas. A chopper or shredder is all that is needed to prepare the organic material, which needs to be broken up into short, mixable, 6-inch lengths.

Mixture Proportions. Three different mixture proportions are used to form the clay roofing material. First, in order of mix, a "structural" batch is: 15 shovelsful of soil (1-part clay to 4-parts sand), 10 gallons of water, 2 gallons of bitumen, 5 shovelsful of coarse sawdust, and 10 shovelsful of chopped grass. The water, bitumen, and soil are thoroughly mixed together to make a slurry. Then sawdust and straw is slowly added. These proportions should produce a mud-like consistency that will show no standing moisture, but one that is wet enough to be troweled in place with ease.

Application. The stabilized clay is applied about 2 inches thick across the bamboo gridwork. A form made of 1/4-inch masonite pegboard is attached to the underside of this grid. It is temporarily braced in position with boards and props. Pegboard has many

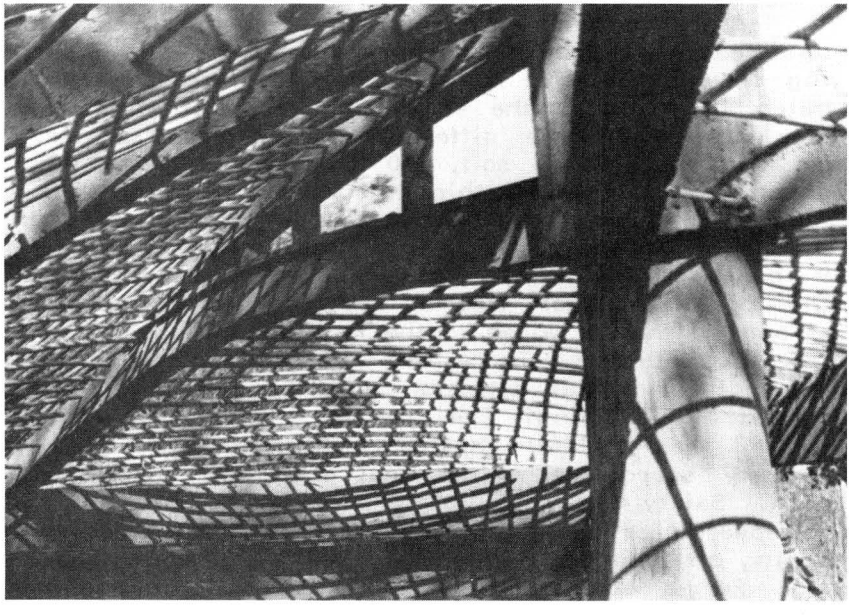


FIGURE 6.17 Bamboo roof panels in place.

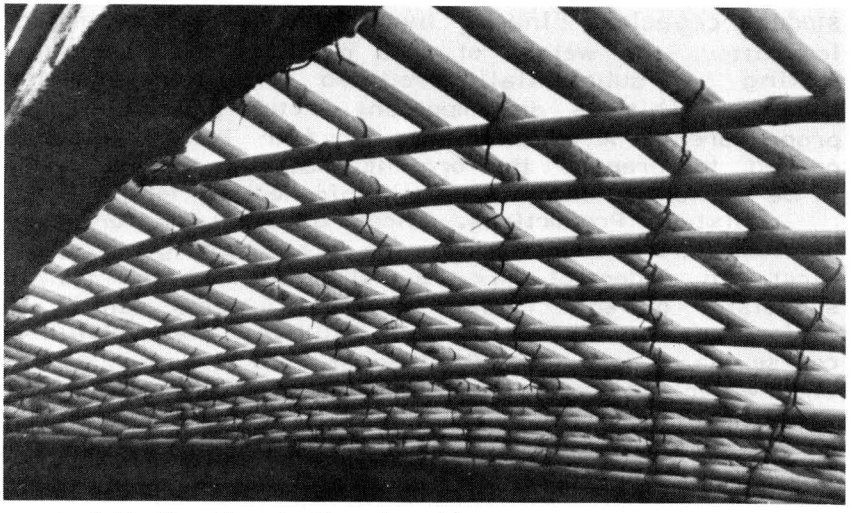


FIGURE 6.18 Wire ties at alternate grids.

advantages as a roof form. It is available in large 4 x 8 sheets and is flexible enough to make compound curves. Numerous holes are convenient when the pegboard must be tied to the bamboo grid; they also permit moisture release.

As soon as the structural layer of clay roofing has been cast over the bamboo framework, an insulating layer of clay is applied over the first. This batch is mixed in the same sequence, but the material's proportions are different: 10 gallons of water, 1 of bitumen, 10 of soil, 10 of sawdust, and 10 of straw. A final 2-inch-thick structural capping that is the same as the first batch is then applied over this insulating layer of clay for a total panel thickness of 9 inches at the edges. This capping layer spans over the top of the roof beams, covering the second layer of bamboo that is wired to the first layer.

Roof Design. There are several reasons why we have given special attention to design of the roof for our studio building. The cost of a roof represents 40 percent of the total expense of a structure. It is a primary source of winter heat loss and summer heat gain. Safety, too, is of critical concern, for roof collapse is primarily responsible for injuries occurring during an earthquake.

For a structurally sound clay roof, panels must have double curvature, so that loading will be transmitted directly to and be absorbed by roof beams.

Through vertical cross section, the triangular-shaped beams bear the lateral thrust of roof panels that act as would a huge keystone for a masonry arch. Furthermore, horizontally, each triangular-shaped roof panel is supported along each of its three sides. (A rectangular-shaped panel is structurally less stable than a triangularly-shaped one.) With curvilinear-shaped structures, roof sections divide nicely into triangular shapes. The total thickness of our roof panels is 9 inches at each edge; 5 inches at their center. This varied thickness, should adequately transmit the forces of compression and shear and should withstand bending moments. A thinner panel, even one formed with double curvature, will lack the degree of stability attained by this panel shape.

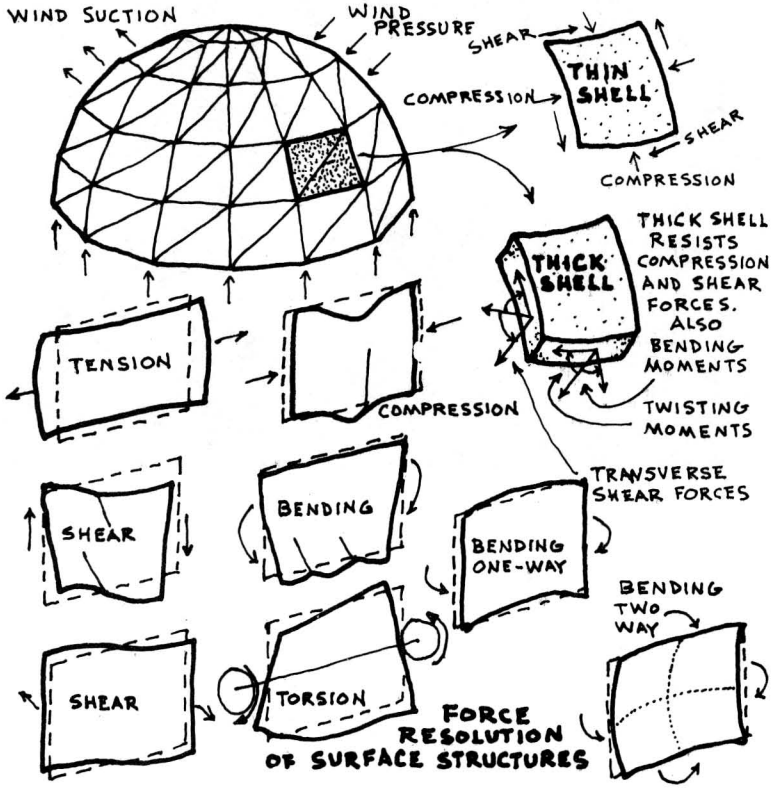


FIGURE 6.19 Shell forces.

Evaluation and Additional Application Tips. Casting a bamboo-reinforced clay roof was unlike any construction experience we have ever before encountered. We especially enjoyed working with this material, which is exceedingly responsive to troweling while forming the compound curves that provide strength for the roof. But a few "happy mistakes" were in order and taught us some important lessons about using this type of building material. We found it important to cast the roof in the heat of summer. Long, hot, dry days are mandatory for proper curing of the clay. With optimum weather conditions, the masonite forms can be removed in three days.

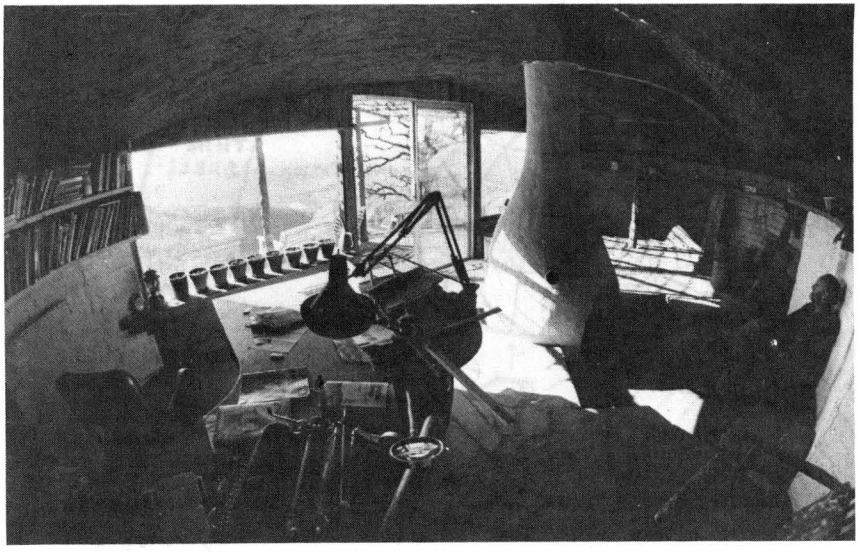


FIGURE 6.20 Completed interior.

The ceiling surface is plastered using the same proportions of clay and chopped straw as were used for the first and the capping layer for the panels. It is also important to securely wire the bamboo edge members that lie alongside the beam, for they transfer much of a panel's weight to the concrete beams. Also, on one occasion, we experimented by leaving off the top layer of bamboo; the panel collapsed. Thus we learned how important this top course is to the panel's strength and how important it is to frequently wire

the two layers of bamboo framework. The upper course of bamboo paneling rests directly over the concrete beam.

Our clay roof panels have never been tested for strength by conventional means---other than having a number of friends gleefully bounce on them at the same time. They seem strong enough, and we feel quite secure working beneath them. One test of their viability occurred the first winter after the studio was completed. An unusually cold, wet storm deposited 18 inches of fresh snow over the structure one night, but not even a hairline crack appeared in the panels.

FIGURE 6.21 Roof load test.

Waterproofing. Allow the clay roof panels to sun and air dry for several weeks before waterproofing them. Our method is the same for the roof as well as the walls of this underground structure. We brush coat the surface with bitumen and wrap it with a layer of open-mesh glass fabric for reinforcement. We then trowel on a 1/4-inch-thick coat of plastic roofing cement. This material is made of heavy bodied asphalt blended with inert mineral fibers. It spreads easily in warm weather and produces a tough, elastic film that will not crack or break loose with age. While the

mastic that coats each roof section is still "tacky," spread a layer of 90-pound mineralized roofing material over the area. The mineralized surface of this material protects both the felt roof paper and the asphalt wall coating to give long-lived waterproofing.

Other Details. The roof overhangs the south wall and clerestory windows of this structure by a foot. To cast this overhang, extend the top layer of bamboo that spans over the roof beam and tie it to a bamboo edge member. The resulting overhang will be 2-inches thick. Masonite pegboard is wired beneath the edge piece to make a form. Once roofing felt has been applied over this surface, embed metal flashing in a bead of mastic and cover the joint with a strip of glass fabric also laid in mastic. A sheet metal shop can fabricate this flashing strip, the vertical face of which should extend slightly beyond the bottom of the overhang and at least 2 inches above the surface of the roof to give a total of 5 inches of exposed face.

FIGURE 6.22 Mastic and fabric application at roof edge.

This flashing is sufficient to hold a thin layer of mixed leaf mold and soil. Vermiculite and sawdust are also excellent materials for this purpose. Three

inches of any similarly lightweight, "fluffy" roof covering will reduce summer temperatures on this roof surface by 20 degrees Fahrenheit. An additional factor of insulation is given by ground cover growing around the perimeter of the building and over the roof and arbor as well. Eighty percent of the available incident solar radiation can be absorbed by this foliage. During the heat season, as moisture transpires from the leaves of ground cover, evaporative cooling lowers surrounding air temperature. Choose plants with a dense, reflective leaf surface for additional advantage.

The final phase of building our underground studio involved fitting window glass and laying the slate flooring. To lay the slate was a relatively straight forward process, except that we used the same stabilized clay formula as mortar beneath the pieces of slate instead of the usual concrete mortar commonly used for this purpose. As each piece of slate was embedded in clay, joints between them were raked. When the slate was set, these joints were filled even with the top of the slate by a mortar mix of fine sand and cement to assure a hard-wearing floor surface. Lamp black was added to this mortar finish to complement the dark color of the slate.

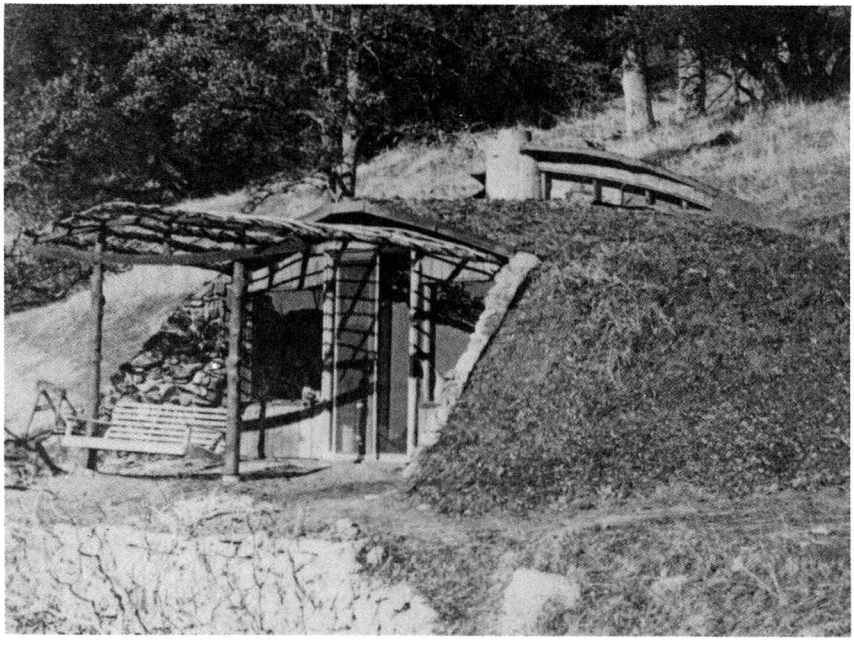


FIGURE 6.23 Completed exterior.

Final Comments. We have no reservations about recommending this method of construction as a low cost housing alternative---as long as you, the builder, first experiment with a small structure before attempting a sizeable house. You will soon learn whether working with curved walls, arched beams, and bamboo-reinforced clay roofing really suits your temperament as a builder. You may experience, as we did, the pleasure of working with a soft, flexible material and responsive building techniques and hand tools. Below are several design sketches applicable to the construction methods discussed in this chapter. They are probably best studied for use in rural parts of this country---beyond building code jurisdictions.

FIGURE 6.24

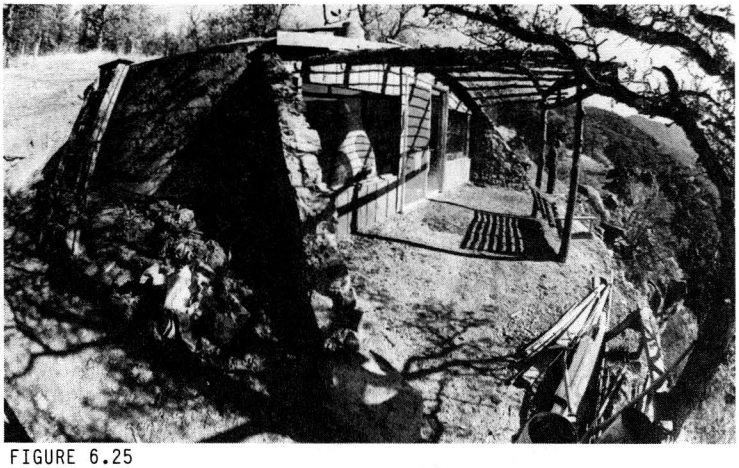
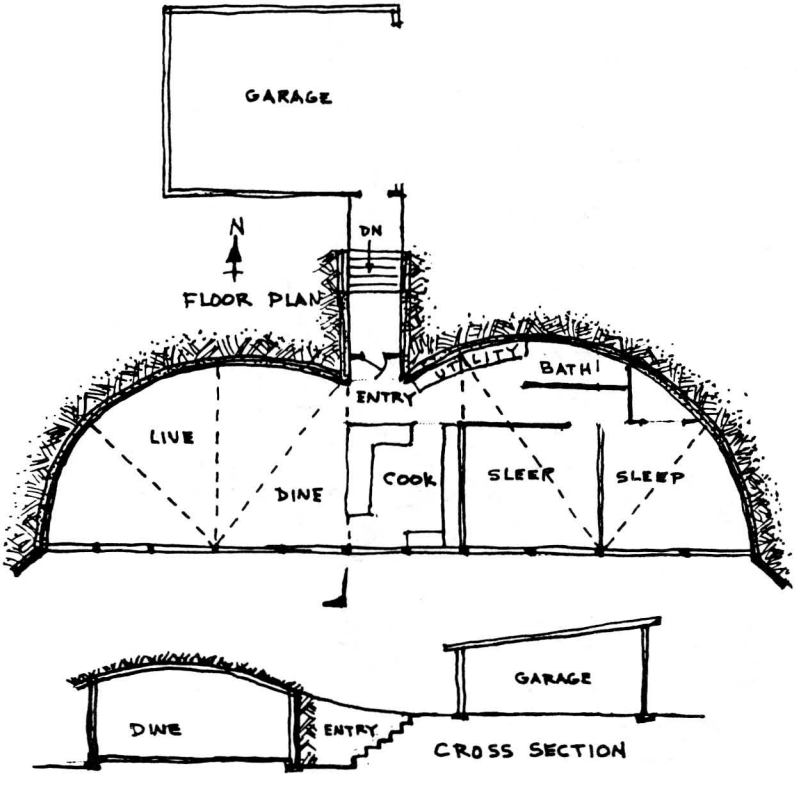
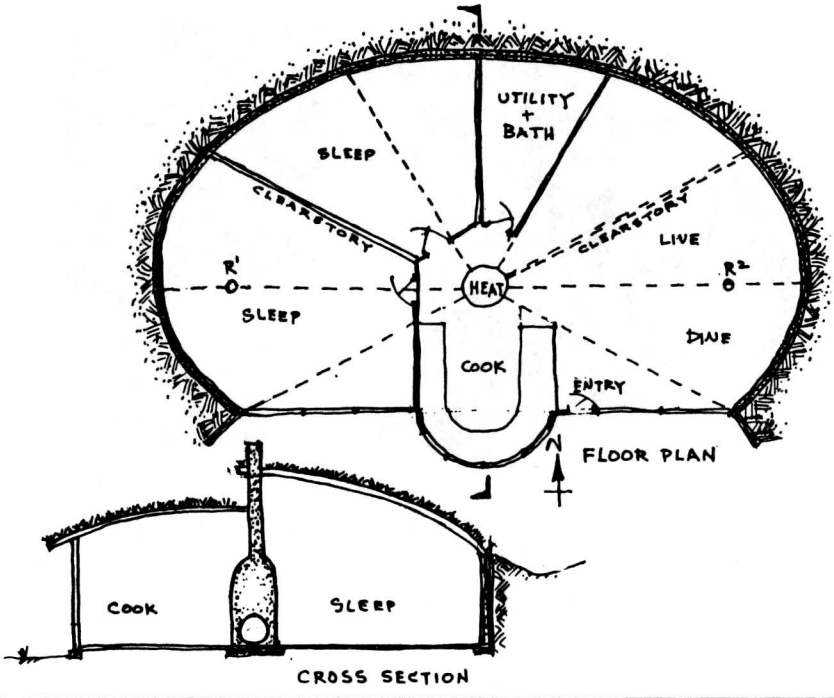


FIGURE 6.25

EARTH SHELTERED CURVILINEAR HOUSE DESIGNS




UTILITY + BATH
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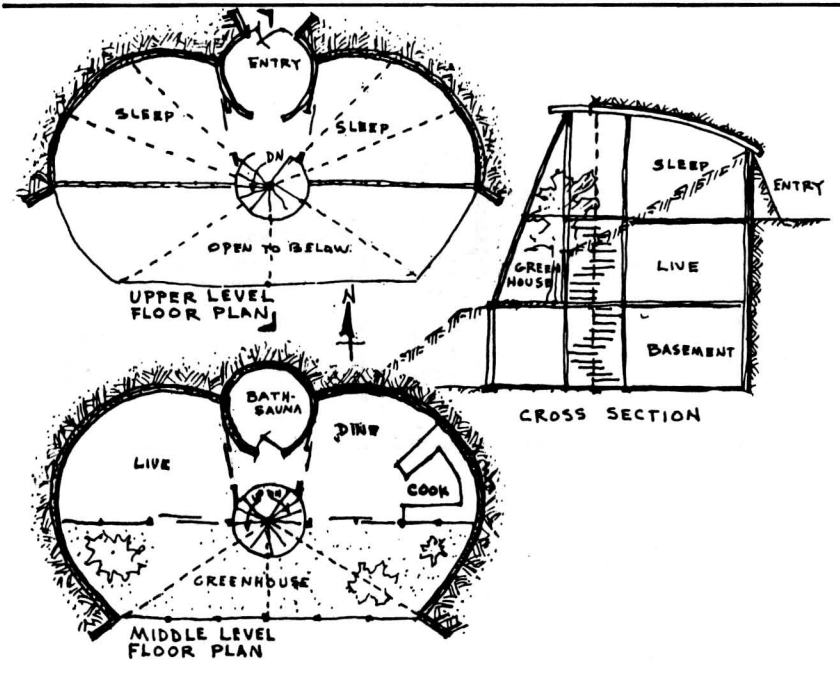
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COOK
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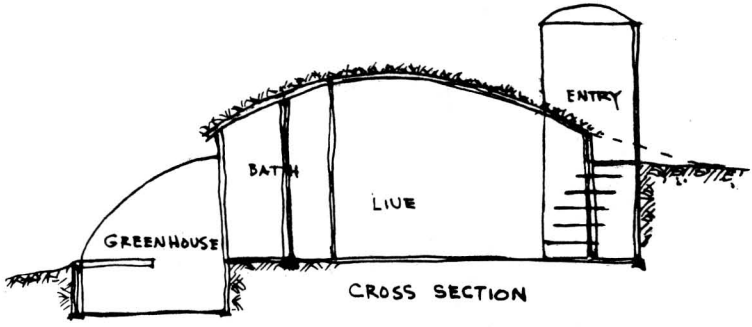
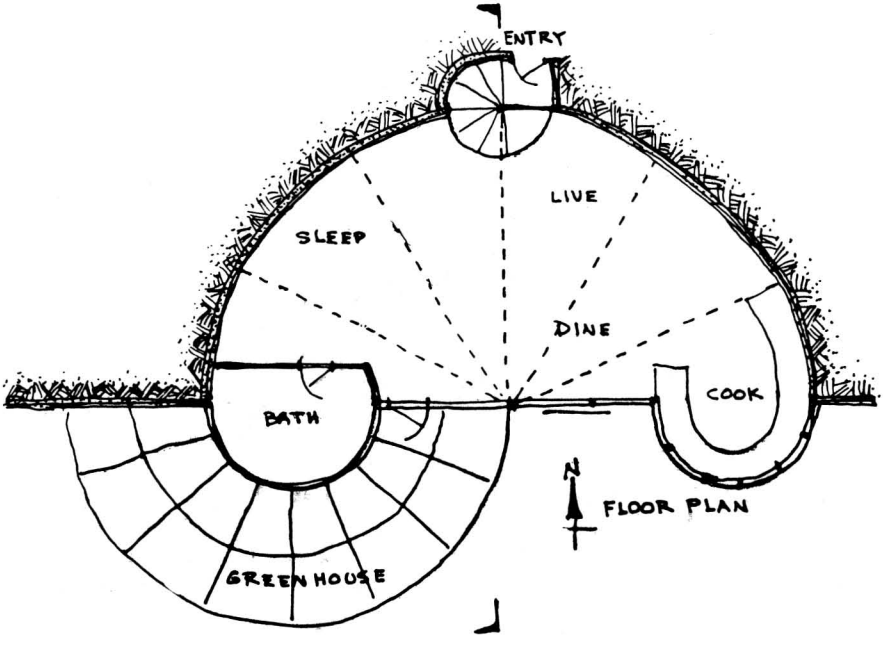
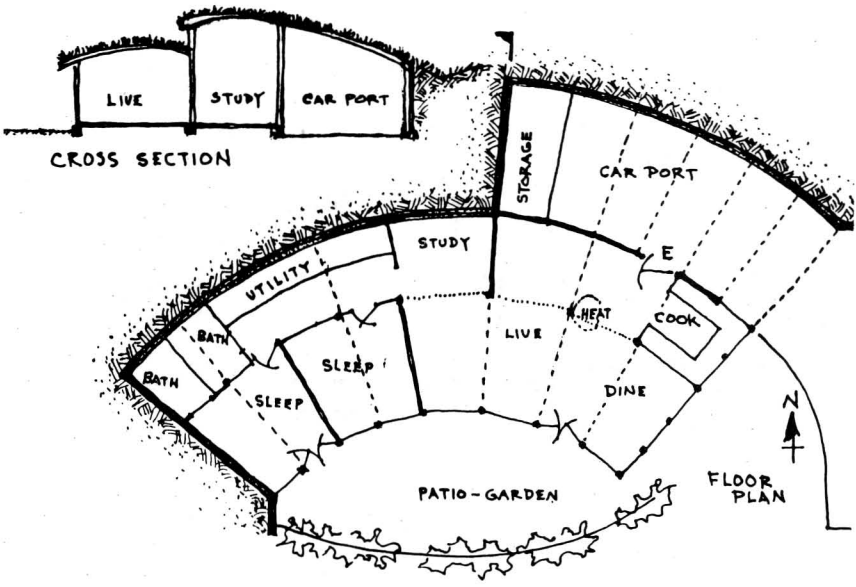
MIDDLE LEVEL FLOOR PLAN



CROSS SECTION



FLOOR PLAN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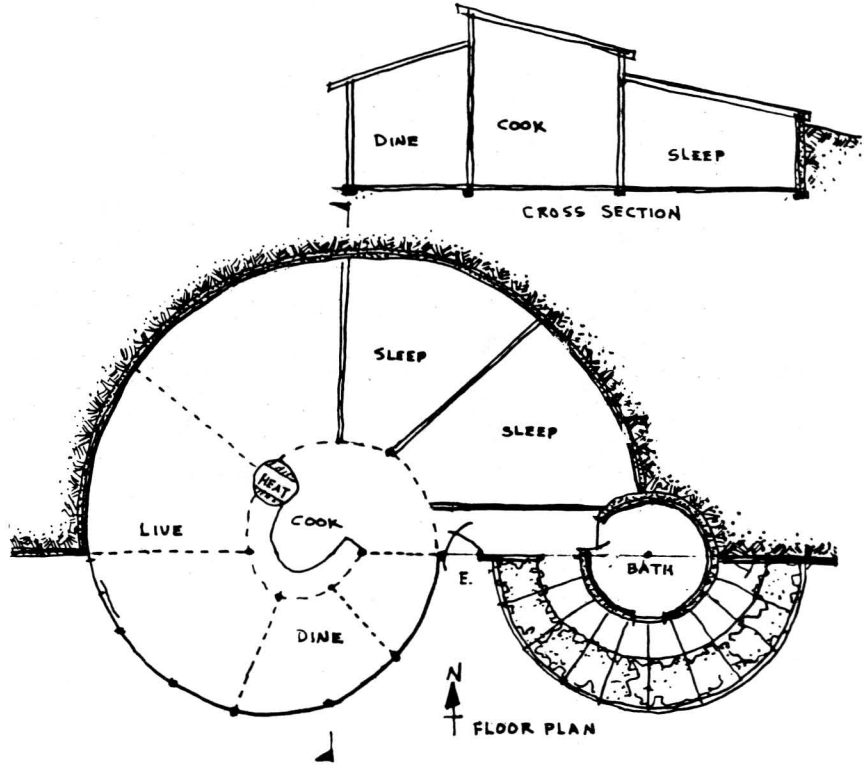
DINE
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Chapter 7

Earth Sheltering and Convective Loop Houses

A new hybrid of passive solar architecture has emerged in recent years. Called the convective loop system, the double shell house, or the double envelope house, the design is controversial, drawing as many critics as enthusiasts. The loop heating and cooling system has attractive possibilities when combined with earth sheltering. Free to employ unconventional building techniques, the owner-builder is in a good position to make use of this system's potential. Studying its mechanics will sharpen the reader's understanding of passive solar and earth sheltered housing design.

The double shell or double envelope house is actually two houses---a house within a house. The space between these two shells is called the convective loop. This continuous passage way allows air to circulate freely over the roof of the inner shell, between the two north walls, under the floor in the basement or crawl space, and up through a south-facing greenhouse or solarium to complete the circuit where greenhouse and roof meet. East and west walls of the house are solidly built, superinsulated, and any windows in these walls are triple glazed, or double glazed incorporating insulating shutters.

Air flow in the loop is powered by convection; there are no fans or pumps to drive it. The circuit is designed to handle air moving slowly, in contrast to a mechanical system that forces air through ducts at a rapid rate. Hence, the convective loop does not produce drafts, noise, or the dust that accompanies a conventional heating system.

The Heating Cycle. During the heat collecting phase of the cycle, the sun warms greenhouse air, which expands, rises, and enters the space between

the two roofs. As this heated air travels toward the north wall, some of its warmth is taken up by the materials of the attic air space and stored in their thermal mass. The air cools and contracts, becoming more dense. It flows down through the north wall air space, loses more of its warmth to that wall, becomes more dense, and eventually drops into an under-floor crawl space or a basement.

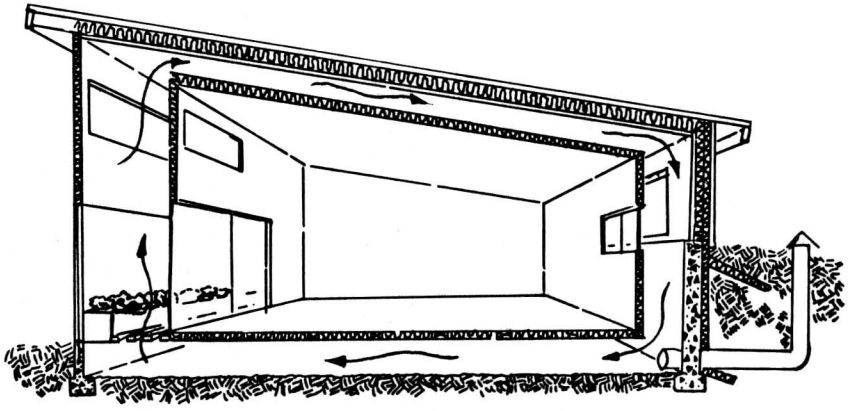


FIGURE 7.1 Conventionally framed convective loop home showing heating air flow.

The weight of air is the driving force for this system of convected air movement. Greenhouse air expands, rises, and "pushes" air along the south leg of the circuit. Air cools, contracts, becomes heavier, and "pulls" as it falls through the loop to the crawlspace. Thermal storage mass is provided by building materials in the loop and in the crawl space or basement. In the latter, air loses the last of its warmth to the soil and flooring of a crawl space, or to the walls, floor, and ceiling of a basement. Finally, cool air is drawn up through floor grates into the greenhouse, where it is heated again. It makes this circuit as long as the sun shines into the greenhouse. Each time the circuit is made, the air transfers heat to the storage mass of the loop.

At night, loop air circulation is reversed. Air is cooled by conduction of its heat to the large glass surface of the greenhouse. Cooled air sinks through the floor grate into the crawl space and is warmed by

heat held in the thermal storage mass (earth, flooring, etc). It then rises up the north wall of the loop, circulates up through the air space in the roof, and re-enters the top of the greenhouse where the circuit begins again.

Lee Porter Butler, one of the originators of the double envelope design, claims that stable earth temperature is the principle source of heat for the loop system. When outer wall insulation extends down 8 to 10 feet into the soil, earth temperature inside this perimeter will maintain air temperature in the loop at 45°F. or above, according to Butler. The idea of tapping geothermal heat stores is an appealing one, but there is debate about whether this is what actually occurs in the crawl space. In one double shell house, it was found that 80 percent of its heat was stored in the roof and the north wall. Less than 10 percent of the household heat generated was stored in soil beneath the building.

The highest proportion of greenhouse heat stored in the underfloor area to date was 40 percent, achieved in a convective loop house built in Ipswich, N.H. by Hank Huber. Concrete blocks were laid on their sides in the crawlspace and air was circulated through their hollow cores. The increased thermal storage capacity was a function of the increased mass of the blocks and the greater surface area exposed to circulating warm air from the greenhouse. No measurable amount of heat was derived from stable earth temperature.

Humidity control is one advantage of the loop system. Earth mass stores the excess humidity that collects in greenhouse air. When the cycle reverses, moisture is released back into drier air and humidity is kept at a healthy level.

The Cooling Cycle. In summer, the convective loop is used to "pump" hot air out of the house. A vent at the top of the loop is opened. This can be a clerestory window to which hot air rises and escapes. Replacement air can be drawn through a series of steel culvert pipes, called "cool tubes," that are laid underground on the north side of the house. Fresh air is pulled through screened ends of these tubes. This air loses any warmth it may have to the metal culvert as it is drawn into the house. Earth surrounding the tubes can absorb large amounts of heat, reducing outdoor hot air temperatures to comfortable levels.

However, cool tubes may cause problems during humid summers. Condensation in the tubes creates a

moist environment where mildew and mold flourish. The tubes can also function during winter to pre-warm exterior air. These tubes have had random success: the best performance was attained when the tubes were over 400 feet long and more than six feet deep in the ground. Many envelope houses do not include cool tubes and the convective loop system does not depend on them.

There are a few books about this intriguing system of passive heating and cooling. Ekose'a Homes and The Double Shell Solar House were written by proponents and builder/designers of convective loop houses. Superinsulated Houses and Double Envelope Houses is a frankly skeptical survey of convective loop homes written by William Shurcliff, a leader in solar and conservation analysis.

The Convective Loop and the Owner-Builder. All of the homes using this system of air tempering are conventionally framed structures. The space comprising the loop is usually stud framed and covered with sheet rock. The owner-builder need not build this way, however. Why build two structures, one inside the other, when one is sufficient?

Many builders of double shell systems are trying to lower the cost of envelope housing to that of conventional homes. However, of the three convective loop homes visited by the authors, all had cost overruns. One, bid at $85,000, ended up costing $115,000. Owner-builders cannot risk beginning similar projects for which even professionals' estimates are far exceeded by actual costs.

Still, there are features of the double shell system that may be advantageous to the owner-builder. Major benefits of the system are:

---Increased surface area for thermal storage, providing more even heating in winter, more moderation and stability in summer.

---Humidity control, whereby underfloor earth absorbs water vapor from moist air and releases it to dry air.

---Increased circulation that freshens stale air.

Earth sheltered housing also offers these benefits. The double shell house is said to reduce heating needs because the living area of the inner shell is protected from outside temperature extremes. The same is true for earth sheltered houses. In these houses a double shell is unnecessary along the roof and north wall where the earth berm functions to moderate wall surface temperatures.

Design hybrids, based on these principles, may use a greenhouse, solarium, thermosyphoning air panel, or a Trombe wall to drive air through this system. Air along the south wall of the house heats and rises. Cooler air is pulled from beneath the floor to circulate around the loop.

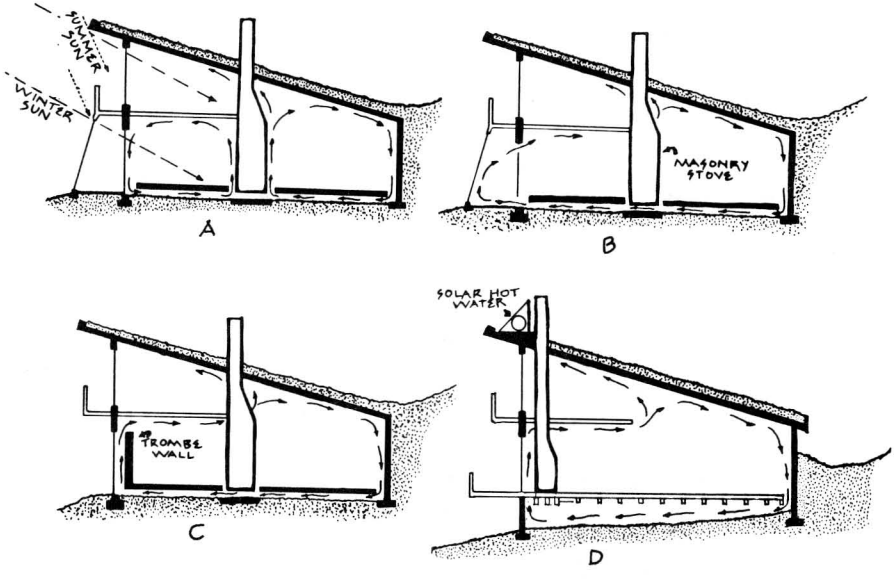


FIGURE 7.2 Design hybrids.
A---Wood heated air flow.
B---Solar heated air flow, using greenhouse or solarium.
C---Solar heated air flow using Trombe wall.
D---Masonry stove doubles as Trombe wall.

The same design also functions well with a wood-stove as a backup source of heat. Both the solar and wood heat sources circulate air through the loop. Air, circulating beneath the floor, is brought within range of optimum room air temperature, and draftiness is reduced.

When heating with wood, vents connecting the loop with the solarium are closed. Air circulates only about the living space. Excess humidity, stored in the earth under the floor, is released into the wood-heated dry air.

Plunger Pile Floor. For the thrifty owner-builder, the building system that may make this plan possible is called a plunger pile floor, a concept developed by Dr. Billig, an associate at the Central Research Institute in Indiana. Although Billig's design calls for piles placed as much as 3 feet apart in both directions, owner-builders who have laid such flooring feel that closer spacing of the piles results in a stronger floor.

A 1-inch thick plunger pile floor is an effective and economical alternative to laying the 3 or 4 inches of concrete slab commonly found in houses today. Its advantages are: it provides a continuous air space between the floor and soil under the building, it uses less building material, it requires less labor to build, and it is more resilient beneath people's feet. The subfloor air space is a bonus for buildings heated and cooled by circulating air. It is especially suitable for use in earth-tempered housing design.

We quote artist/cartoonist Jim Schmalzried, who provided the detailed sketches that accompany this narrative of his successful plunger pile floor project.

"Official data on the strength of the plunger pile floor is not currently available. I wouldn't recommend this system for heavy duty use as barn, garage, or shop floors, but I am confident that it can be used for home interiors under normal conditions without risk. Great savings in materials can be realized with a plunger pile floor. Mine cost me thirty-five cents per square foot at 1980 prices.

"This floor system has other advantages besides being low cost. The sub-floor space that is created insulates the floor and prevents moisture from rising through it. Thus it remains warmer and drier than conventional concrete flooring. Cold room air drops through floor registers spaced around the perimeter of a room and travels beneath the floor to an uptake duct placed alongside a centrally located heating unit. Here, the air is warmed, rises, eventually cools, and then drops to begin the cycle over again. This system of circulating cooler air beneath flooring eliminates foot-chilling drafts.

"I put my floor in after the exterior walls and the roof of my building were completed. This arrangement works nicely because the area is protected from weather, and the apparatus used while forming the piles can be hung from ceiling joists.

"The first stage for building a plunger pile floor

involves rototilling the soil of the area to be floored. This plowing fluffs up the earth so that after the floor is completed, the soil will gradually settle and leave an air space. The floor slab will then be supported solely on its piles. After rototilling, the area should be leveled using a straight edge in the manner used to screed a concrete slab. Use sand to make a smooth surface if your ground is rough.

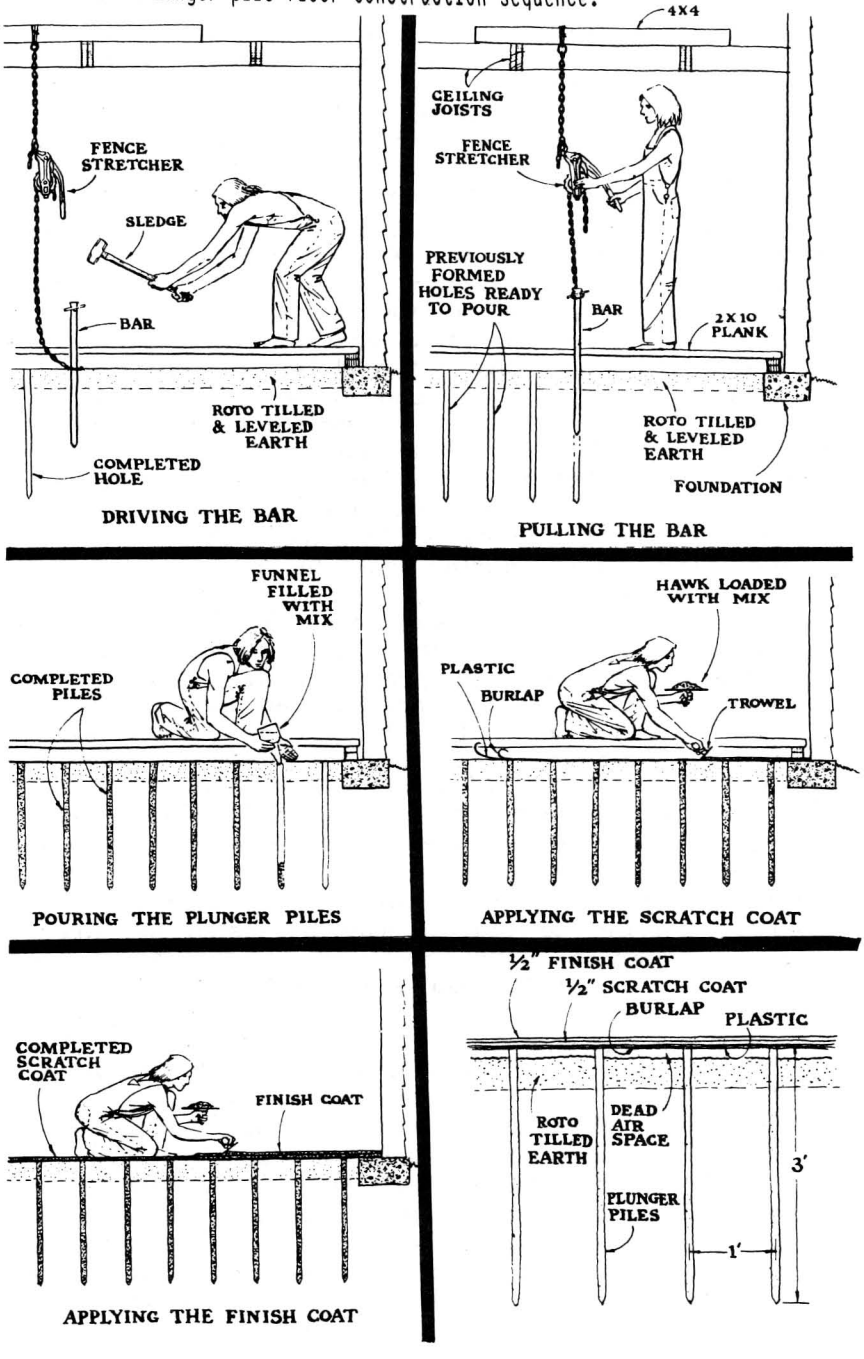
"The same mix of 1-part cement, 3-1/2-parts sand, and 10 percent lime is used for the floor slab and these piles. It is necessary when pouring the 1-inch-diameter piles to use a mix of watery consistency so that this material will flow easily into the holes and completely fill them. Use a funnel for this operation.

"When all piles are poured, cover the area with a layer of plastic to create a moisture barrier between the soil and the floor. Then cover the plastic with a layer of burlap cloth to give the slab needed reinforcement. Make sure there are no creases or folds in either of these layers of material for this could weaken the floor. Burlap can be purchased by the bolt from a fabric store.

"Next, apply a scratch coat of concrete to the floor area. Technically, this is a stuccoed floor surface rather than a poured concrete slab. Two 1/2-inch-thick coats of stucco mix are applied using professional plasterer's tools, the hawk and the trowel. A coarse well-graded sand and a minimum amount of water needed for a plastic, workable mix should be used. A straight edge, made of 1/2-inch plywood, is useful for leveling this concrete flooring to the desired thickness. Before tackling a similar project, I would recommend that the owner-builder lay a small sample area of flooring so that it may be tested for strength before proceeding with the rest of the floor. This section can be broken up and checked throughout for proper thickness.

"Before the first coat of stucco hardens, it should be lightly scratched to improve the bond between it and the finish coat of concrete to be laid over it. Smooth the surface of the second coat and keep its surface damp for a week while the concrete cures. All of these steps, from leveling the area, forming and pouring the piles, laying the plastic and burlap, to applying the finish coat of concrete, are done with the builder working from planks that rest on the building's perimeter foundation wall. This is done so that the fluffed up soil isn't compacted by footsteps

FIGURE 7.3 Plunger pile floor construction sequence.



or equipment. The tilled earth beneath the floor will settle once the floor is completed, creating a sizeable air space.

"Once the first scratch coat of stuccoed flooring has cured for a week, it will support your weight so that the finish coat can be applied without the need to work from planks. Do not trowel this coat excessively, for doing so will bring water and cement to the surface of the slab and create a soft, easily marred floor. With two people working together, one mixing and the other troweling, an area of about 100 square feet can be laid in one continuous operation in three to four hour's time. For optimum strength, each coat of stucco should be applied in a single, uninterrupted aplication. If your floor area is larger than 100 square feet, as mine was, it can be divided into smaller sections spanned by concrete floor beams. The finish coat should be damp-cured for a week as well. The floor is ready for use in a month. Good luck."

The plunger pile floor would complement a convective loop system of heating and cooling. If earth is to be used as the storage meduim, the space between it and house flooring must be narrow, as it is with the plunger pile floor. If the space is too deep, as in most crawl spaces or basements, air will move slowly and stratify, storing heat only in structural members. Thermal storage and humidity control by the earth would be lost.

Convective Loop Problems. A criticism of the convective loop design is that it creates spaces that are inaccessible to adults but not to children (and their toys), to squirrels, raccoons, skunks, mice, rats, moles, gophers, insects, snakes, and birds. By eliminating all but the under-floor space, this problem ceases to exist. If an animal should wander into the narrow plenum beneath a plunger pile floor and die, the entire system could be closed off until the decay process was completed. In this design, the house would not depend solely on the loop for its heating. Passive solar features and wood heat would still function when the loop was closed off.

Fire hazard has been a major concern in convective loop houses. After inspecting a conventionally framed double shell house, the Maryland Fire and Rescue Bulletin concluded in an article entitled "Conservationists Dream.....Firefighter's Nightmare" that, "...any fire within the 'convective envelope' could be expected to spread rapidly to involve the entire dwell-

ing. Persons within would find themselves inside an oven, with escape limited to the side walls if these contain usable openings." In some envelope houses, industrial fire dampers with fusable links and smoke detectors have been placed in the loop. However, the loop under the plunger pile floor contributes in no way to any fire hazard. Neither the earth nor the thin concrete slab will burn.

There may be an opportunity for the adventurous owner-builder to design a full loop system in a house. One attempt using earth tempering in a low cost, self-built construction is currently under way in northeastern Texas. This design has a double, slip form, concrete back wall with a 4-inch air space that connects directly to an air space running beneath a plunger pile floor. Air, passing through a network of 4-inch air ducts embedded in stabilized clay roofing, flows through this cavity in the building's slip formed walls and then into the subfloor air space. Cast-in-place concrete beams, shown as dotted lines in the drawing, provide support for the clay roof panels. A south-facing greenhouse is the heat source that creates air movement through the shell of this structure.

FIGURES 7.4-7.6 Low cost convective loop home using plunger pile floor, now under construction in northeastern Texas.

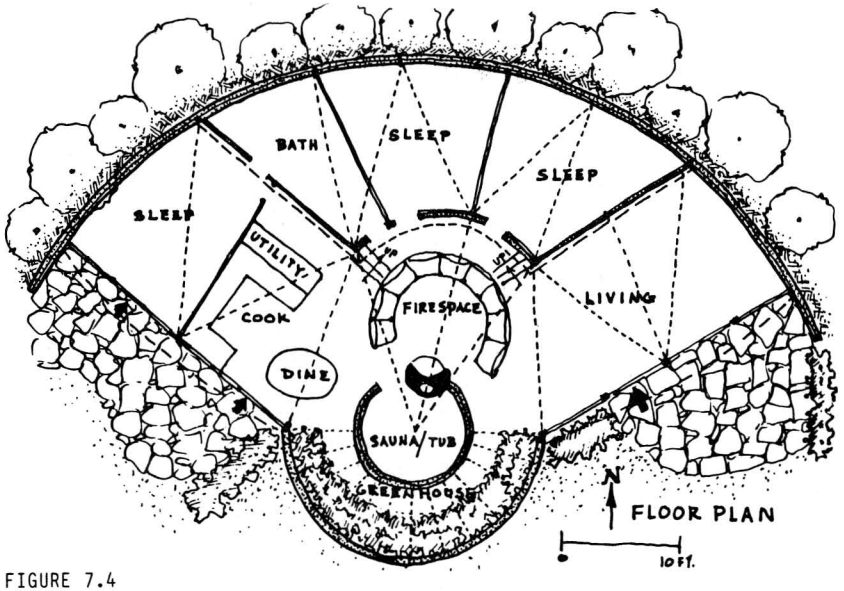


FIGURE 7.4

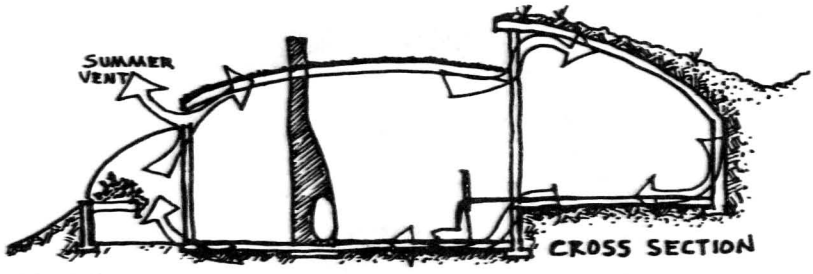


FIGURE 7.5

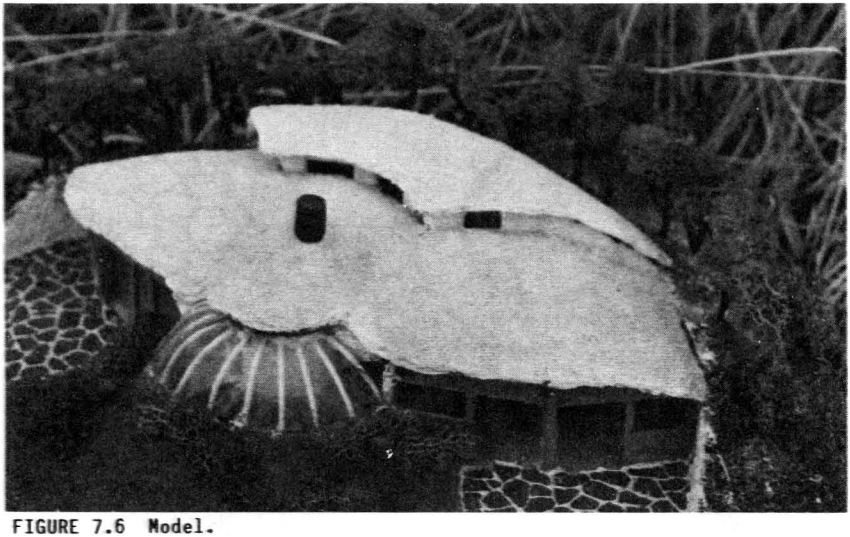


FIGURE 7.6 Model.

FIGURES 7.7–7.10 Curvilinear underground house design with convective loop air circulation.

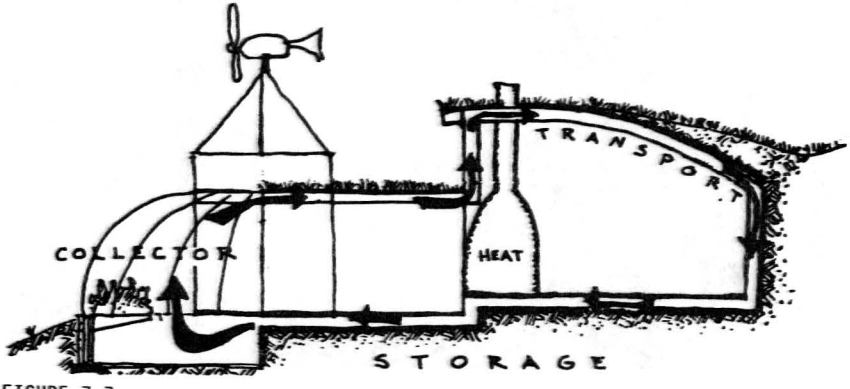


FIGURE 7.7

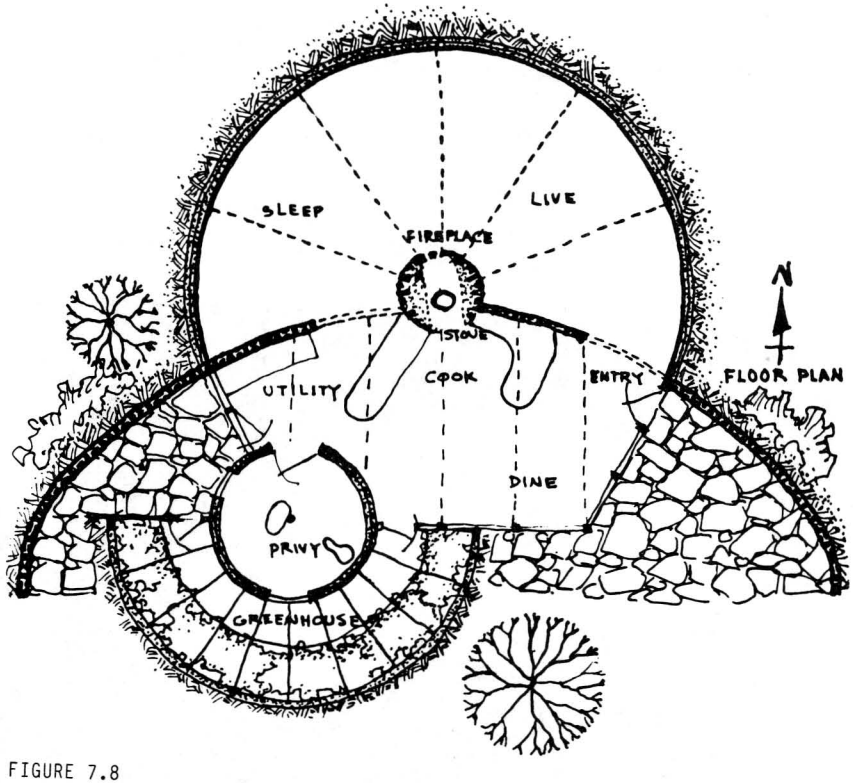


FIGURE 7.8

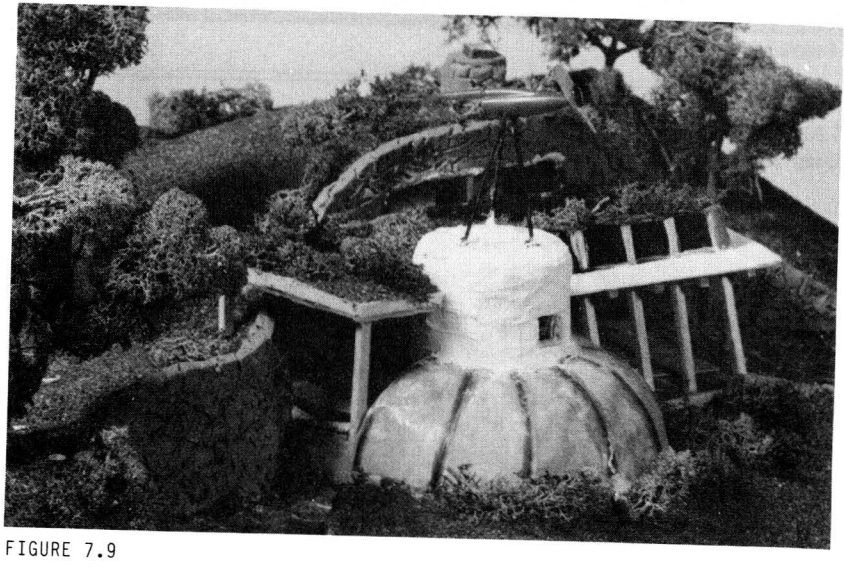


FIGURE 7.9

Chapter 8

Conclusions

The idea of underground housing generates excitement. Books and magazine articles abound on "going underground" with shelter. The motivation for peoples' interest is genuine enough; it is an honest search for housing that is energy efficient, affordable, healthy, attractive, and in harmony with nature. A shelter form with such obvious connections to the earth would appear to fulfill this purpose.

But most contemporary underground house designs fail to satisfy these needs. What we are getting from experts is suburban houses covered with dirt.

Historically, underground building was practiced where special site conditions favored subterranean construction. In arid lowlands of Tunisia, villagers at Matmata dug their homes thirty feet deep in soft sandstone. These inexpensive shelters served to temper the extremes of heat and wind encountered in this climate. Present day subsurface homes dug into loess belt soil in China preserve rich farmland and shield people from ferocious winter winds, and their price: hard work. Andalusian and Aegean cave dwellers and Native American Pueblo builders found subterranean conditions favorable to low cost shelter construction. Responding to unique climate conditions, these indigenous peoples sheltered themselves comfortably and economically underground. None were well-paid designers indulging in fashionable "solutions" for a wealthy few.

Only recently has our reliance on manufactured products, like plastic membranes for waterproofing, concrete and steel for structure, and forced air ventilation equipment, made building underground feasible on virtually any site. For that reason alone, we might be suspicious of the current wave of enthusiasm for underground housing. Many of these materials have not been tested for their effectiveness over time or for their ecological impact and possible toxicity.

All new housing concepts invite critical examination. In the present rush to build a more ideal house, designers and architects advocate one or another solutions that in fact deal only with a small

aspect of the larger problems. Like commuters arguing about which is the most fuel-saving car, they propose ever newer models: earth sheltered, superinsulated, double envelope, active solar, geodesic, passive solar. Excesses of modern suburban housing are unacceptable in any form, for the same reason that a more efficient auto fails to solve our transportation problem.

New directions for housing are needed. The change we foresee must be as sweeping as the change in eating habits advocated by Francis Moore Lappe in her book, Diet for a Small Planet. Can we design a new housing ethic for a small planet? The construction of a new house can no longer be viewed as an isolated event but must be seen in its global context, with world-wide ramifications for all people. Lappe connected starvation around the planet with the choice made by a few to buy factory-farmed, grain-fattened beef and pork. Similarly, suburban housing construction and maintenance consume a disproportionate amount of available resources and energy. Suburban sprawl also depends on our continued use of private means of transportation. A true accounting of energy shows that the solar home dweller who drives a private vehicle to work uses more energy and resources than a person living in an inefficient downtown apartment who commutes on public transportation.

Today's "energy efficient" houses touted in numerous books and articles are, for the most part, oversized, overbuilt, and overpriced. They are suitable only for the ecologically unaware person wealthy enough to build one of these dinosaurs in the idealized rural setting in which they are unfailingly pictured. In our opinion, such housing is built for the acquisitive on an ethic of greed, not need.

Once considerations of community, workplace, and transportation are addressed and political connections between them are drawn, examples of appropriate housing are few. Models to inspire us and mentors to guide us to real alternatives are scarce. While a major change in diet may be gradual and allow us daily experimetation, only a few have more than one opportunity in a lifetime to build a new house.

A battery of socio-economic institutions add momentum to the trend for indulgence and excess in housing. Colleges train young designers and architects to embrace a false aesthetic of building design, one that relates little to real function or cost and until recently even omitted awareness of solar cycles. The percentage-

based professional fee schedule leaves little incentive for the designer to create small or efficient housing. Manufacturers encourage people to buy more and use more. Slick advertising lures consumers to believe that a rewarding life depends on purchase of the newest commodities. "Indispensible" products usually turn out to be expensive, untested over time, and sometimes toxic. Unions encourage people's reliance on workers in the professional trades instead of promoting self-built, self-repaired projects. Bankers endorse self-indulgent housing, for higher prices mean more profit for them. Pressured by these converging influences, building codes enforce overbuilding as the legal standard for all housing. Perhaps the only way to create real alternatives is for owner-builders to forego the professional designer, boycott the manufacturer, side step the licensed contractor, ignore arbitrary codes, and build reasonably enough to pay cash.

This appropriate house, designed and built with good information and intelligence, is a living machine, operated by the homeowner, that responds continually to the outside environment. Sun angles and shading, indoor and outdoor planting, wind direction and air flow all change in a seasonal cycle that never exactly repeats itself. The environment, dwellers and shelter are in rhythmical motion, a dance, the steps of which are best created by a sensitive, aware dancer, the owner-builder.

The Wilderness Scale. A helpful design tool for our purposes is Malcolm Wells' Wilderness Scale. There, the house is examined for its impact on the ecology. The focus of the scale, however, must be widened to encompass a new perspective for housing. Wells' scale judges a house solely by its performance and lacks an analysis of the sources of materials, construction processes, community connections, life-span and end-use. We must broaden our housing ethic to give consideration to those living upstream and downstream from ourselves.

-100 always	-75 usually	-50 sometimes	-25 seldom	+25 seldom	+50 sometimes	+75 usually	+100 always	
destroys pure air								creates pure air
destroys pure water								creates pure water
wastes rainwater								stores rainwater
produces no food								produces its own food
destroys rich soil								creates rich soil
wastes solar energy								uses solar energy
stores no solar energy								stores solar energy
destroys silence								creates silence
dumps its wastes unused								consumes its own wastes
needs cleaning and repair								maintains itself
disregards nature's cycles								matches nature's cycles
destroys wildlife habitat								provides wildlife habitat
destroys human habitat								provides human habitat
intensifies local weather								moderates local weather
is ugly								is beautiful

Malcolm Wells' Wilderness Scale was first published by Progressive Architecture in 1971. Says Wells, "...until we human beings regularly earn positive scores we'll be sinking deeper into trouble."

When gathering building materials the first choice can be site-available resources---wood, soil, rock, or sand. Site-generated materials require little or no transport, have low energy content*, are non-toxic, and require no packaging.

The Wells' scale disregards the construction process so important to the owner-builder. Construction need not be hazardous or toxic. The choice of appropriate materials, technique, and work pace will enhance the builder's health and well-being. Innovative housing built with local labor and materials can enrich community skills and knowledge. Children should be encouraged to participate in safe procedures as basic shelter education.

*"Energy content" is an energy accounting of a material from its source to its end-use. For example, tempered float glass requires one third the energy to manufacture as acrylic glazing materials. Glass is made from natural, essentially unlimited resources---sand, soda ash, dolomite, limestone, and salt cake. It has a longevity several times that of acrylic glazing materials, does not easily scratch, and does not burn. Glass can be recycled, and blemished panels can often be purchased cheaply.

A house should be durable and long-lasting, its maintenance easy, and components accessible and repairable. A well-cared-for structure will last centuries, but when its useful life is over, it should be possible to recycle or compost it. At the very least, a house should not present disposal problems caused by toxic wastes or large piles of useless material.

Size and efficient use of space are important. In nature, animals, birds, and insects build only the size shelter they need. The size of human habitat is too often dictated by desire instead of need. Spaces with a single function, like bedrooms or dining rooms, may be eliminated in favor of more efficient multi-use areas. We might begin by borrowing concepts from the international marketplace of ideas, in particular from the Japanese, who live in small homes with style, grace, and economy.

The house you will build has personal, cultural, and world-wide implications. Expensive housing puts a tremendous burden on the owner. Owner-built houses of site-generated materials, finished in affordable increments, could relieve years of anxiety created by indebtedness.

Expenditures have repercussions rarely considered. Dollars spent are much like ballots cast; each dollar reinforces the cultural pattern in which it circulates. Cash outlay may strengthen local industry and support local craftspeople, or purchase of goods from a franchise outlet will concentrate wealth outside your community.

This concept has connections to the world-wide economy. Every consumer purchase will strengthen either local fruitful economies or exploitive international economies. Multinational companies extract money from the local area of the consumer and often exploit the resources and labor of the producer in the Third World nations. For example, to build a masonry stove you may hire a local mason and use site-available stone, or you may purchase a discount chain store copy of a Norwegian-designed wood stove of Taiwanian steel manufactured in Singapore. Tracing a product from its source to its eventual use is revealing. Communities become strong only when they receive our support.

A house is best considered in its social context, in its pattern of use. It should be close to your workplace, to schools, social activities, and sources of supplies. An isolated home, though deserving of a

good rating on the Wilderness Scale, could burden community services (roads, schools, etc.) negating its virtues of energy-efficiency and self-reliance. Houses may be located to encourage walking and bicycling rather than the use of private cars.

Simple, efficient home space can promote a sense of centeredness and contentment in the individual. It can be an expression and embodiment of community cooperation and creative work.

We present these considerations in chart form below. They are intended to complement Wells' Wilderness Scale, which will continue to inspire us to consider our impact on the ecology. We simply wish to draw a wider circle.

MATERIALS	
site-available and site-processed	manufactured and imported
recycled or renewable resource	limited, non-renewable resource
low energy content (eg. adobe)	high energy content (eg. aluminum)
little handling and no packaging	much handling and wasteful packaging
natural, non-toxic materials	excessive use of solvents, glues, foams, and other toxic substances
CONSTRUCTION PHASE	
used hand tools	required heavy machinery
benign process, little safety equipment needed	unsafe, noisy, toxic workplace
	protective devices necessary
process enhanced health	hazardous process resulted in injury
preserved soil and plants	undue damage to plants, soil compaction, residue damage from concrete, solvent and paint cleanup, etc
knowledge and skills bank of local community increased	specialized work force imported, contributing nothing to local richness and diversity
included participation of children	excluded family and friends
THE HOUSE	
small, compact, efficient	extravagant waste of space
areas have many uses	single function spaces
durable, long-lasting	will not survive 30 year mortgage
easily maintained	difficult or unsafe maintenance
repairable	planned obsolescence
final disposition recyclable or compostable	toxic material or waste disposal problem
increases flora and fauna diversity by creating special alcoves and microclimates for multi-purpose plants*	monoculture, vulnerable to disease and pest

*Some plant uses are: summer shade, wind protection, food production, herbs and spices, beauty, fragrance, honey bee forage, nitrogen fixation, etc.

PERSONAL, CULTURAL, AND WORLDWIDE RAMIFICATIONS	
low cost	enslaved to mortgage
cash outlay to local craftspeople or local industry	concentrated wealth outside local community, contributed to exploitation in Third World
close to workplace, schools, social life, supplies	suburban home or rural retreat burdening community services**
encourages walking or bicycling	necessitates private car
captures solar energy for space heating, hot water, lighting, electricity	dependent on electrical grid, imported oil, nuclear power, gas pipelines
part of decentralized energy grid of moderate value, self-reliant and easily defendable, does not require military capability to defend	depends on expensive centralized facilities and complex transmission system, vulnerable to breakdown, saboteur or vandal, requiring military defense, paramilitary presence for protection
promotes clarity, contentment, simplicity, centeredness, joy	complications and problems create irritation and frustration, encourages self-indulgence and egoism, creates anxiety from indebtedness

**A suburban or retreat home may overburden roads, sewage, power lines, mail delivery, etc., or reduce watershed holding capacity, overdraw ground water supplies, make a fire hazard, etc.

Definitive conclusions about owner-built underground housing based only on our promising examples would be a disservice to the reader who is preparing to build a home. Some owner-built and contractor-built underground houses have failed, and even the successful homes have not yet withstood the test of time. The three small shelters examined in this book were chosen because they tested different construction methods and were satisfactorily completed. By sharing information and experiences, more owner-builders will be able to successfully build underground.

Earth-sheltering attracted us a few years ago because it appeared environmentally attractive, conserving both energy and the landscape. Our experience building underground has made us more aware of the complexities of subsurface construction, and more cautious about recommending it. Even the ecological appeal of underground building may be deceptive in two ways.

First, more excavation is required in underground building. The necessary heavy machinery can easily damage surroundings by compaction, lack of operator skill, or carelessness. Excavation must be carefully planned. For those who would tread lightly on this planet, earth sheltering may leave too heavy a footprint. Light construction methods might be considered, such as pole framing which does not even require a perimeter concrete foundation.

Second, heavier construction is mandatory underground due to greater structural loads imposed by earth berms and sod roof. Rigorous drainage systems and waterproofing barriers are necessary. More concrete, steel, gravel, tar, plastic pipe, and waterproofing materials are needed. The gravel quarry, sand pit, cement plant, steel mill, oil refinery, and chemical plant all have to be taken into an accounting of the ecological impact of an underground project.

Early and oversimplified claims of exclusive underground energy efficiency have been toned down. Heavily insulated buildings that are sealed from air infiltration and provided with thermal mass function well above or below ground. Mass for thermal storage may be placed around the outside of the insulated space as the earth blanket surrounding the underground home, or thermal mass may be placed inside any solar house in water walls, Trombe walls, masonry stoves, tile floors, etc. All will function well if designed and built correctly.

Many phases of underground construction are complicated. Unfavorable site conditions, soil type, and ground water can halt plans to build below the earth's surface. Drainage and waterproofing for a building that is not accessible for repair is challenging. There have been both success and failures with every available technique and material. Only time will reveal their relative reliability.

For the owner-builder, this means that an underground home is probably the most difficult and risky type of shelter to choose. Extra attention is necessary in all phases of planning and construction, including site and soil analysis, daylighting, ventilation, safety procedures, and landscaping.

The owner-built underground houses illustrated in this book were well-built for reasonable cost. Their price varied from a few hundred dollars total cost for Forestiere's shelter to $3 per square foot for the Kern studio, less than $15 per square foot for the Mullan

home, and under $30 per square foot for the Zanetto residence. The cost varied inversely with the amount of labor each owner-builder invested, the quantity of site-generated materials available and the extent of hand tool use.

In our technological society, we each have a vast range of choices to make regarding use of our material richness. We can use the power of our wealth to accumulate and aggrandize our possessions or we can live more simply and gain enjoyment from the natural world. The earth sheltered houses portrayed in this book express some seed ideas for the decisions we must make if we are to create in the future a sustainable society based on renewable resources.

When these choices are made thoughtfully, it is then that earth sheltering offers an expression not allowed by any other building technique. Built in harmony with nature rather than against her, and suited to the needs instead of the greeds of the dweller, the underground home can be a statement of a fruitful lifestyle, set in the earth amid the richness and beauty of life that only this small planet offers us.

Epilogue

The Native American Example

North American Indians were among the indigenous people of the world who built earth sheltered houses. Some of them were the Mandans of the Great Plains, who lived in earth lodges made of log posts thickly covered with hard-packed grass and dirt, the Navajo in their brush and soil hogans, and the Pueblo adobe cliff dwellers with subterranean kivas. Readers are urged to research the native building structures of their own area, to examine the site-generated materials used, and the means and attitude held while gathering those materials. Here in California, many tribes built round, excavated log frame buildings, bermed and often covered with dirt. Structures ranged in size from sweat houses of small diameter to community ceremonial lodges 70 feet wide. Before several feet of earth were dug out, these buildings were literally "laid out" for a specified number of men stretched out on the ground, head to toe. to determine the building's diameter.

The following description of the building of an earthen dance house was told in 1936, by a seventy-year old Nomlaki Indian, Jeff Jones. The tale is

excerpted here from a very lovely book entitled The Way We Lived: California Indian Reminiscences, Stories and Songs, edited with commentary by Malcolm Margolin.*

When they want to build a dance house, all the important men get together in the elkel (chief's house) and talk about where they can get the trees. They have all the posts and ribs of the structure named, and the men mention the various logs they have seen that would meet the needs of the different parts. They do not speak of their decision to anyone, but go out and look at the tree that is to form the center pole. They will walk around the tree and examine every detail of it.

Before any further steps are taken, the group goes to the captain of the village and asks his approval of their plan. He will not answer them for a long time, perhaps as much as an hour, and then he may ask them if they are in a position to build a lut (dance house). They will tell him what food they have in store. He will ask, "How do your women feel?" and they will reply that it is all right with them. This procedure is necessary because it is expensive to build a dance house, as they must feed all the neighboring people who assist in the construction and are invited to the dance that follows. The headman can (theoretically) stop the building of a house. Others might object to it, but their only protest is to move to another village.

Having decided to build a house, the men begin to prepare the poles. These are cut down, trimmed, and barked, a fork being left at the top. The cutting of the poles may take a month. Finally they select a place to dig the hole for the dwelling, and by this time the people have caught on to what is in the air without being told, and those who are next to the important men come to help.

The house is built in one day. The people have gathered and brought what food they could. They all get to work digging out the pit, each person working by digging with his sen (club) and carrying the earth out in the conical carrying baskets. Each works in that portion of the excavation toward which his

*BUILDING A DANCE HOUSE. From "Nomlaki Ethnography" by Walter Goldschmidt. University of California Publications in American Archaeology and Ethnology, Vol 42 (4). Berkeley. 1951. Page 422. Narrated by Jeff Jones.

own home lies. By working hard together, they finish the hole in three or four hours. Everyone helps, women, children, and men---all but the menstruant girls.

Then important men have meanwhile gone to the location of the center pole and have dressed it as a dancing man with a feather headdress. It is carried to the house pit by six or eight men on a "stretcher" made of grapevine, accompanied by two singers, who sing a "march." They do not set the pole down till they get to the hole, where they set it upright in a special way and tamp it into place.

Next they put the two "brothers" in place and then the other upright posts; then the ribs are put from ground to post and between posts, a man being ready at each joint to do the lashing. Then smaller sticks and finally wormwood are added, each person again working on that portion lying in the direction of his home. After the wormwood is laid over the ribs, the crannies are stuffed with moss, and earth is carried onto the roof and spread over it to a thickness of about three or four inches. It is packed down by constantly walking over it, so that in the end the house is nearly airtight except for the door and smoke hole. At the last the people from the several surrounding villages try to finish their side first, and this work is done in high spirits, the people teasing and making fun of one another. Those first finished raise a great shout and help the others to finish the work.

The house is completed by night, and after this there is either feasting or a "sweat" or both. The hosts are expected to feed their guests for some time, and usually their entire supply of food is exhausted by the occasion.

We find in this brief narration inspirational elements of the Indian building experience. Primary is the importance of community: the lodge is planned, built and used by all the people, including women, children and friends. The act of building strengthens the community order and neighborhood relations. We sense great respect for the materials, in harvest, construction and use. The support posts become family members, honored by name and song.

The entire building process emphasizes the interconnectedness of all things; the ritual context illumi-

nates the sacred nature of each action and every participant. Enthusiasm infuses the construction and celebration that follows, unifying the people, the structure, and the earth itself in the joyous dance of life.

This subterranean lodge was constructed at Grinding Rock State Park in the Sierra foothills of California. The basic frame is similar to the one described in the narrative, except this roof was made of sections of bark taken from standing dead trees.

California had an indigenous population approaching half a million, representing many diverse and very localized tribes. Yet, there are few traces remaining of the Indian cultures, which prospered in California for at least a thousand years. Their methods of construction come to us through the preservation of some of the oral tradition. These people lived as lightly on the earth as the plants and animals that sustained them. A millenia of indigenous culture leaves less archeological evidence than will any one of the four ecological buildings described in this book.

The history of how our culture decimated the native people is an ugly one, often ignored and forgotten. The disruption of the delicate and diverse ecologies of California is still happening before our eyes. We cannot return to the old ways of Indian traditions, but we can honor that heritage and perhaps redeem our own. We can discover again ways of building and living that respect the full circle of life, the natural flow of creation and decay. There is a soft path to the future, waiting to be taken.

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Credits

Photos and drawings.

George Ballis, 1.13, 1.15, 1.20
Bob Brooks, 1.1, 1.2, 1.10, 1.11
Michael Eckerman, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 1.16, 1.19, 6.20, 6.23, 6.24, 6.25
Frederich Von Frauhoffer, 3.12, 3.13, 3.14, 3.15
Jan Goldman, 5.3, 5.7, 5.8, 5.12, 5.16, 5.17, 5.22, 5.25, 5.27, 5.29, 5.31, 5.35, 5.44, 5.45, 5.51, 5.52, 5.53, 5.54, 5.60, 5.63, 6.4, 6.5, 6.7, 6.11, 6.13, 6.15
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Jim Schmalzried, 7.3
Underground Space Center, 4.4
U.S. Gypsum 3.16, 3.17, 3.18, 3.19
Jim Zanetto, house sketch, 4.1, 4.2, 4.3, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15
All other photos and drawings by Ken Kern and Jane Mullan.
Typeset in the living room with an Olivetti 231.
Headlines, photographic screening and reductions by Tim at North Star.
Cover design and text format by the Mullans and Ann Ackerman.
Cover photos by Lansom Moles.
Cover typeset by Typographics.
Printed by Delta Lithograph, Van Nuys, CA

Anyone further interested in the design methods of Guy Rottier or Jim Zanetto may contact them at:

Guy Rottier
c/o LABAN
Belvere 06450 Lantosque
France

Jim Zanetto
2459 Creekhollow Lane
Davis, California 95616

Appendix

EARTH SHELTERED HOUSES AND BOMB SHELTERS

Underground shelters are occasionally recommended as protection from nuclear war. We authors believe this is a cruel deception whether advocated by government or private sources. Our reasons are clear.

There is no such thing as limited nuclear war. The Soviet Union has been consistent in saying once the exchange has begun, it cannot be limited. The U.S. is targeted by 8,000 warheads delivering 10,000 megatons.

One sixth of the U.S. land mass would be subjected to extreme heat creating an inferno equal in intensity to the WWII Dresden firestorm in which bomb shelters became crematoria. Three quarters of our land mass would reach incendiary temperature levels. Only shelters hundreds of feet deep with independent sources of oxygen would withstand the initial flash and burn.

What would there be to return to? Average radiation levels reach 10,000 rads in a 10,000 megaton attack. Lethal dose ranges are: mammals 250-1000 rads, conifers 1000 rads, deciduous trees 2000-10,000 rads. In short, everything dies except insects and grasses. In addition to this short-lived bomb radiation (cesium-137, strontium-90, etc.), all the 200,000 tons of fissionable material housed in U.S. military targets (including nuclear power plants) would be dispersed, compounding the initial 10,000 rad dose with the long term radioactive fallout of plutonium and uranium.

Ozone breakdown, another result of nuclear war, endangers even the survival of insects and grasses. There is no habitat that could sustain human life under these conditions.

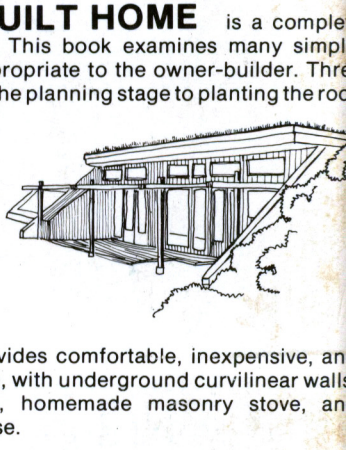
We must all learn the facts. Read Fate of the Earth by Jonathon Schell, The Final Epidemic edited by Adams and Cullen, Nuclear Madness by Dr. Helen Coldecott, or Nuclear War: What's in It for You by Roger Molander. Solutions cannot come until we understand the problem.

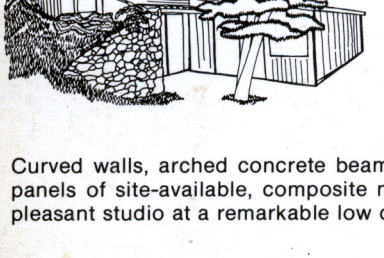
The task of our times is to devise political and social structures that will allow the people of the world to survive in harmony and cooperation. Building energy-efficient, self-reliant houses begins to eliminate dependence on international economies and competition for scarce resources. That is the only way an earth sheltered home can offer protection from nuclear holocaust.

On the cover and above is the grape arbor entrance to Baldasare Forestiere's inspiring undergroun garden. Created by a master owner-builder, this seven acre house and garden complex is featured i text and photos.

THE EARTH SHELTERED OWNER-BUILT HOME is a comple guide to the beauty and efficiency of underground living. This book examines many simpl innovative and low cost designs and methods especially appropriate to the owner-builder. Thre successful earth sheltered homes are presented in detail, from the planning stage to planting the roo

This suburban home features a treated wood frame and foundation, saving money, simplifying owner-building and achieving well documented energy efficiency.





This rural home provides comfortable, inexpensive, an beautiful living space, with underground curvilinear walls timber framed roof, homemade masonry stove, an expansive greenhouse.

Curved walls, arched concrete beams, and vaulted roof panels of site-available, composite materials create this pleasant studio at a remarkable low cost.

Barbara and Ken Kern have been in the forefront of the owner-builder movement for three decades Among their many popular books are *The Owner-Built Home, The Owner-Built Homestead, Ston Masonry, The Owner-Built Pole Frame House,* and *Ken Kern's Homestead Workshop.*

Jane and Otis Mullan have worked with the Kerns on numerous projects since the early 70's. The previous owner-built home was featured on the cover of "The Mother Earth News."

$9.95

ISBN 0-910225-00-